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POLLUTION PREVENTION, AN INVESTMENT
DECISION MODEL TO ASSESS FINANCIAL
FEASIBILITY FOR APPLICATION
TO AIR FORCE PROCESSES

THESIS

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AFIT/GEE/ENV/92S-15

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THESIS

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Abstract

This research develops a Pollution Prevention Investment Decision Model (PPIDM) to evaluate the financial feasibility of pollution prevention alternatives.

The PPIDM provides managers with simple, systematic, and flexible guidelines for making accurate and expedient decisions when considering pollution prevention alternatives. The model illustrates that a comprehensive analysis is not always necessary.

The PPIDM gives managers the flexibility to adjust the economic feasibility criteria based on top management's perceptions of the political environment. When top management places a very high value on political considerations, economic criteria is insignificant and the project may be implemented immediately without further analysis.

The PPIDM takes an incremental approach which allows managers to evaluate projects by considering data in increments beginning with management's interpretation of subjective considerations. This approach to project feasibility analysis enables environmental managers to make quicker decisions without sacrificing accuracy.

This model also provides guidelines for estimating spill liabilities using probabilistic analysis. This procedure has potential for estimating other liabilities such as regulatory fines and penalties.

This research includes an aircraft depainting case study to illustrate the PPIDM and exemplify the benefits of pollution prevention. Although the study specifically addresses Air Force activities, it has universal application.

POLLUTION PREVENTION, AN INVESTMENT DECISION MODEL TO ASSESS FINANCIAL FEASIBILITY FOR APPLICATION TO AIR FORCE PROCESSES

I. Pollution Prevention as a Simple Cure to a Costly Air Force Problem

Hazardous Waste Management

Hazardous waste management is a costly problem to the Air Force. In 1990, the Air Force generated 43.5 million pounds of hazardous wastes. Once generated, hazardous waste must be treated, stored, transported, and disposed of in accordance with a myriad of federal, state, and local laws and regulations. The Air Force paid approximately $19 million for disposal in 1990 alone (38).

Each year, hazardous waste compliance laws become more strict which translates into escalating management costs. In fact, the cost of hazardous waste disposal grew from $600/ton in 1987 to $6,700/ton in 1991 (44). There is every indication that these costs will continue to rise. Furthermore, with the vast amounts of hazardous waste the Air Force handles, funding requirements for disposal and spill site restorations grew from $132 million in 1986 to $398 million in 1992 (43). These growing costs make pollution prevention an attractive alternative to hazardous material/waste management.

Cost effective solutions to hazardous material and waste management problems will always attract top management's attention. Smart environmental managers are converting to pollution prevention technologies which are low cost alternatives to pollution control and management. The sooner managers implement these technologies, the sooner pollution management costs will go away. This research provides managers with a decision making tool which enables them to make quick and effective choices regarding alternatives to pollution management.

Pollution Prevention

The objective of pollution prevention is to reduce, or preferably avoid, generation of pollutants at their source (41:13; 9:130). The pollution prevention concept replaces the traditional end-of-pipe or top-of-the-stack pollution control concept.

Unlike pollution controls, pollution prevention technologies reduce or eliminate the problem of pollutant transfer from one environmental medium to another (26:3,22). For example, carbon adsorption pollution control equipment removes hazardous volatile chemicals from air and collects them on carbon filters. These filters must then be properly disposed of as hazardous wastes. Pollution prevention technologies, on the other hand, eliminate the need to use hazardous volatile chemicals in the first place. By avoiding pollution altogether, hazardous waste compliance

and future remediations or liabilities are no longer problems.

A Pollution Prevention Example. A common industrial process that generates a significant volume of hazardous waste is aircraft paint stripping. Traditional paint stripping uses hazardous solvents to remove paint from aircraft and aircraft parts. This practice is costly in terms of hazardous waste produced, hazardous waste management required, and possible remediation requirements for accidental spills or leaky disposal sites. Worker exposure to traditional paint stripping chemicals pose significant health hazards and associated liabilities.

New paint stripping technologies use carbon dioxide pellets or plastic bead media to eliminate the need for hazardous cleaning solvents. Non-hazardous, benzyl alcohol based strippers are also used in certain aircraft depainting applications. Benzyl alcohol is a harmless chemical commonly found in perfumes, deodorants, and baby lotions (45:1). The removed paint is the only sludge material requiring special handling.

Although these technologies demonstrate technical pollution prevention possibilities, the question of financial feasibility remains unanswered (16:21).

Problem Statement

The purpose of this research is twofold:

1. To develop an investment decision model to quickly and effectively evaluate the cost effectiveness of pollution prevention alternatives.

2. To apply this model in a case study to illustrate its use.

Research Objectives

In achieving the research purpose the following broad objectives are accomplished:

1. To determine the tangible and intangible benefits and expenses associated with the use and management of hazardous solvents, and their waste products.

2. To determine the tangible and intangible benefits and expenses associated with implementing an alternative pollution prevention technology.

3. To develop a simple pollution prevention investment decision model (PPIDM) to evaluate alternatives.

4. To apply the PPIDM to a paint stripping case study.

5. To determine the financial feasibility of solvent substitution technologies.

Research Definitions and Scope

Pollution prevention is a broad term which has many applications for the elimination or minimization of hazardous waste. Source reduction is the optimal application and is defined as follows:

> any practice which reduces the amount of any hazardous substance, pollutant or contaminant entering the waste stream or otherwise released into the environment (including fugitive emissions) prior to recycling, treatment or disposal; and reduces the hazards to

public health and the environment associated with the release of such substances, pollutants or contaminants. (25:1)

To illustrate the pollution prevention alternative decision process and economic feasibility, this research considers alternative source reduction technologies, specifically, paint stripping of aircraft and parts.

Thesis Organization

Chapter I develops the hazardous waste management problem and establishes the significance of pollution prevention. Chapter II follows with a discussion of the evolution of the pollution prevention concept and researches existing solvent substitution technologies. Chapter III investigates existing life-cycle cost models. Chapters IV and V develop the Pollution Prevention Investment Decision Model for single and multiple alternatives, respectively. These chapters describe the model's theory in detail. Chapter VI illustrates the use of the model through application to an aircraft depainting case study. Chapter VII summarizes the effort and findings, discusses the model benefits and insights gained during the research process, and concludes with recommendations for possible future research.

II. Evolution of the Pollution Prevention Concept

Introduction

This literature review provides a comprehensive investigation into the concept of pollution prevention and how it is used as a tool for Environmental Management (EM). The purpose, incentives, and benefits associated with pollution prevention within the Air Force are reviewed. The investigation explains why the focus on pollution problems has shifted from pollution control to pollution prevention.

This review discusses the evolution of national, federal facility, and AF attitude and policies. Next, this chapter develops the pollution prevention concept. The specific pollution prevention concepts of waste minimization and source reduction are described and the benefits gained through implementation are discussed. The thesis proceeds into an investigation of the industrial and AF strategies involved with pollution prevention. Lastly, the review addresses specific AF applications of pollution prevention.

Background/Purpose of Pollution Prevention

The objective of pollution prevention is to reduce, or preferably avoid, pollutant generation at the source (41:13; 9:130). This concept takes priority over the common version of pollution control which treats the end products of a process. An analogy would be, "preventing pollution is like preventing disease by changing eating habits and lifestyle;

pollution control is like using medicine and surgery to minimize ill effect" (37:36). The traditional end-of-the-pipe control approach results in limited success, where pollutants usually only shift from one environmental medium to another and are not eliminated (20:8).

Waste Minimization. Waste minimization is a pollution prevention application term which includes source reduction and recycling. Methods of achieving waste minimization are inventory control, substituting less or non-hazardous materials for hazardous raw materials, reuse, recycling, production equipment modifications, use of improved technology, implementation of alternate processes or procedures, and reducing waste volume. (34:1-2).

The Air Force Logistics Command (AFLC) originated a waste minimization program called "PACER REDUCE". The purpose of this program is

> minimizing the weight, volume, and toxicity of hazardous waste generated at AFLC facilities to the degree economically practicable and to ensure that current and proposed methods of treatment, storage, and disposal of hazardous wastes are the most practical methods available and that they minimize present and future threats to human health or the environment. (34:5)

Since AFLC merged into the Air Force Material Command (AFMC), all AFMC bases have adopted "PACER REDUCE" and expanded it into a pollution prevention program (2).

Typical AF-generated wastes include residual fuels, spent solvents, paint thinners, and waste petroleum products. Polychlorinated biphenyls (PCBs), pesticides, and

antifreeze are examples of other wastes addressed by waste minimization programs. Air Force activities which generate wastes include engine test cells, vehicle and aircraft maintenance, fuels research, paint shops, engine shops, golf course maintenance, corrosion control, power production, hospital labs, and others (33:viii, 7-13).

Regulatory Evolution

Over the last 20 years the management of pollution has changed, with the strategy switching "... from pollution control to waste management to waste minimization to pollution prevention" (20:7). This section the environmental regulatory history and includes some specific examples.

Related National Laws. The Resource Conservation and Recovery Act (RCRA) of 1976 regulates the treatment, storage, and disposal of hazardous waste (52). The Comprehensive Environmental Response Compensation and Liability Act (CERCLA) of 1980 regulates remediation activities for contamination resulting from releases and past disposal practices (51)[1].

The first shift toward prevention was with the 1984 Hazardous and Solid Waste Amendments (HSWA), which mandated the institution of a waste minimization policy at federal facilities and industrial firms. It also emphasized source

[1] Several other environmental laws and regulations could be cited as having an effect on the pollution prevention policy; however, this discussion is limited to those mentioned above.

reduction and recycling. In 1986, various hazardous material source reduction and recycling reporting requirements were established through sections 313, 322, 325(c), and 326 of the Superfund Amendments and Reauthorization Act (SARA) (25:10,13).

In 1988, the Environmental Protection Agency (EPA) established the Office of Pollution Prevention (PPO) (20:9). This action marked a change in priorities. The new priority is to find creative approaches to prevent pollution, particularly within industrial processes (20:9; 46:5). The Pollution Prevention Act of 1990 introduced pollution prevention as a national policy (25). This led to implementation of the EPA's pollution prevention approaches. This Act creates the following pollution prevention hierarchy (25:1):

1. Minimize or prevent pollution at the source (source reduction) where practical;

2. If source reduction is not practical, recycle or reuse in an environmentally safe manner;

3. If the previous options are not feasible, treat the pollution in an environmentally safe and permanent manner, and lastly;

4. Dispose of the pollutant in an environmentally safe manner only as a last resort.

In early 1992, the EPA merged the PPO into the Office of Pollution Prevention and Toxics (OPPT) but with the same goal in mind (32). OPPT believes pollution prevention is the preferred approach to environmental protection. Pollution prevention "... is very real, and it involves a

true, cooperative, nonadversarial approach by the agency" (3:53). Even though pollution prevention is not mandated, the Agency is seeking to build a consensus on goals and objectives of pollution prevention that will be most effective. They want all pollution generators to incorporate pollution prevention practices into their organizations. In fact, the EPA itself is integrating pollution prevention into its own programs to ensure pollution prevention receives widest possible application (3:55).

With all of these regulatory initiatives, the EPA states, "we, as a society, must begin to integrate pollution prevention into the way we design, build, buy, and consume" (3:54). As a result, the 1990's will be a turning point. Pollution prevention will be "... the cornerstone of a national environmental protection strategy" (41:23).

<u>Applicable Federal Facility Documents</u>. The 1984 amendment to RCRA mandates that federal facilities comply with federal, state, and local hazardous waste disposal requirements. As a result, federal facilities no longer receive sovereign immunity and compliance waivers unless specifically approved by the President (53).

In 1988, the EPA published the <u>EPA Federal Facilities Compliance Strategy</u> (23). This document requires federal facilities to achieve and maintain compliance with all of the aforementioned laws. It also provides the basic strategy for federal agencies to comply with the laws and

explains the EPA's role of enforcing these laws at federal facilities (23:x). The DOD, in particular, is one of the nation's largest generators of pollutants and wastes; therefore, DOD is adopting pollution prevention practices as standard procedure at their facilities. The Air Force, as a DOD agency, is committed to be the national leader in implementation of pollution prevention policies and practices (50:2). Furthermore, the DOD has technical and research capabilities that allows them to conduct pilot programs to set precedents for other federal agencies and the private sector (24:7-9,19).

Air Force Initiatives. Publication of the United States Air Force Pollution Prevention Policy and Implementation Guidance is the Air Force's most ambitious pollution prevention effort. The Air Force is now committed to

> prevent pollution by source reduction, cleanup existing contamination, comply with environmental standards, incorporate environmental planning into the AF decision process, and protect and enhance natural and cultural resources. (50:2)

The Air Force's pollution prevention guidance includes an implementation guide for effective installation pollution prevention programs and a clear definition of the AF's objectives and goals for achieving success.

Pollution Prevention Benefits

It is easy to see from the environmental regulatory histories and the difficulty with environmental compliance why pollution prevention is now popular. An important aspect of pollution prevention is the potential economic savings due to avoided liabilities and costs for pollution treatment and disposal. Additional savings may result from reductions in direct tangibles such as raw material and manufacturing costs. Pollution prevention eliminates the cost of complying with new and existing pollution abatement regulations and with permitting requirements for waste handling and treatment (34:3; 22:5).

Not all benefits of pollution prevention are direct tangibles. Other incentives include indirect tangibles and intangibles such as: reduced potential for generator liability at treatment, storage, and disposal facilities; reduced handling and transportation which reduces potential liability for spills; safer work conditions which improves employee health and attitudes; and improved image from both the public and employee's perspectives (34:3; 22:5).

The concept of incorporating pollution prevention or waste minimization into industry practices is not new. Industries such as 3M have practiced pollution prevention for many years with positive results (41:15). In fact, "3M's 'Pollution Prevention Pays' program saved over $500M since 1975 and prevented annual discharges of over 1.6 billion tons of wastewater, 120,000 tons of air pollutants,

14,000 tons of water pollutants, and 313,000 tons of sludge and solid waste" (55). The most effective multimedia pollution prevention programs experience the following benefits: lower operating and disposal costs, less need for process changes due to new environmental regulations, less potential for losing market share to competitors who show more environmental sensitivity, less liability, and an image of "good corporate citizenship" (30:133; 9:130).

Pollution Prevention Strategies

All industries, including the Air Force, can benefit from pollution prevention initiatives. Success requires support and commitment at all management levels of the organization (10:125). Pollution prevention often requires modifications to manufacturing processes and operation and maintenance activities. It is possible to produce a low cost, quality product using pollution prevention processes.

There are different categories of effort involved in pollution prevention, ranging from easy to more challenging to implement. The following discussion explains these three categories in detail.

Category 1. The first category of pollution prevention involves easy to implement opportunities with minimal cost and risk. These types of changes deal with the operation rather than the system technology and should reduce operational costs. Examples include good housekeeping, eliminating or minimizing undesirable byproducts, selecting

raw materials that are less hazardous or improve the product's recyclability, recycling solvents and unreacted materials, and maximizing energy efficiency (30:132; 9:132). Some industries also use the "just-in-time" inventory philosophy and only store a minimum amount of hazardous materials to minimize spill potential. They select equipment with low-leak potential and easy maintenance, track raw materials and wastes within the facility, monitor process conditions to avoid mishaps, educate and train employees, and encourage teamwork among the staff (30:133; 5:14; 10:124-125). This category often produces savings that pays for itself within a year. The key to its success is to ensure that employees understand and carry out their responsibilities (37:36; 10:121-122).

Category 2. The next category involves more advanced opportunities. These changes are more expensive because they involve equipment or process modifications and process control. Both internal and external sources of information on wastes and reduction techniques are invaluable at this stage. The project investment costs for this category often take several years to recover through project benefits. These pollution prevention actions require a preliminary economic and risk assessment to ensure the change is worthwhile (37:37; 10:122).

Category 3. The most advanced category of pollution prevention implementation is complex, directly involving the process itself, and likely requires substantial capital

investments for technology and equipment. The initial investment and risk involved are significant and it takes much longer to recover initial investment costs (37:38; 10:122). It may require significant political pressures to make the relative savings appear justified.

Many sources in the literature recommend that periodic waste-reduction audits or assessments be performed for all three categories of implementation to ensure the pollution prevention program is carried out effectively. Finally, companies should pursue new pollution prevention solutions through R&D (37:38). The applications described below deal with pollution prevention implementation for all three categories.

Specific Air Force Applications

The AF has great potential in pollution prevention by changing its way of doing business and making pollution prevention the focus of environmental management actions. Numerous modifications can be made to achieve success with this new strategy. The following discussion describes some progress and success the AF has experienced by implementing pollution prevention.

Environmental Management Strategies. The first requirement necessary for successful pollution prevention implementation is top-level management support from the squadron, wing, major command, and Air Staff levels. AF leadership clearly understands the importance of the

environment. AFMC established Environmental Management (EM) directorates at each AFMC base. Other commands created separate environmental branches within their civil engineering squadrons. The AF clearly stated full support when the USAF Chief of Staff and Secretary of the Air Force signed an action memorandum committing the AF

> to environmental leadership with the goal of preventing future pollution by reducing use of hazardous materials and releases of pollutants into the environment to as near zero as feasible. (49:cover letter)

Next, the base environmental organizations developed a facility Waste Minimization Plan. This plan incorporates facility-specific goals and policies, provides guidance for program implementation, and assigns responsibilities to all involved personnel (34:4-5). Another key was the assignment of multi-disciplined teams to implement the program. To achieve successful implementation, personnel are properly trained, position descriptions identify individual waste minimization responsibilities, and incentives are offered for finding ways to prevent or minimize waste (28:89-91). Part of the program includes internal self audits to see if the program is carried out to its maximum potential. An information exchange has been started to share pollution prevention successes and lessons learned throughout all federal facilities (28:91).

Technology Review. There are numerous ways to easily and economically prevent or minimize wastes; however, the following paragraph is limited to discussion of examples of

new, higher level technologies that are making significant pollution prevention improvements within the AF:

Many Air Force bases now have management information systems (MISs) which track chemical purchases and use. These systems enable the environmental organizations to track quantities and types of hazardous materials used basewide.

Tinker AFB employs new technologies for parts cleaning and paint removal which use carbon dioxide pellets (CO_2) or plastic media beads blown under high pressure. These avoid the need for hazardous cleaning solvents and aircraft paint strippers (14:79).

AFMC recently awarded a contract for design and development of a Large Aircraft Robot Paint Stripping (LARPS) system which performs the paint stripping operation more efficiently. This technique reduces hazardous waste generation, worker exposure, and stripping costs. The robot uses non-chemical stripping processes, such as high-pressure water and/or CO_2 pellets in controlled motions (7:21).

Other examples of new AF pollution prevention strategies are Ion Vapor Deposition (IVD) which replaces cadmium electroplating for corrosion protection of aircraft parts and reduces cadmium waste generation by 95%; nontoxic, biodegradable cleaners which replace hazardous chemicals for aircraft parts cleaning and degreasing; and the use of compressed natural gas for vehicle fuel which reduces ozone forming pollutants by 50% (21:27,29,34).

Waste solvents, generated primarily through aircraft paint stripping and parts cleaning, are one of the AF's largest hazardous waste streams. A significant amount of research is dedicated to finding alternative stripping and cleaning technologies, and substitute solvents. A few of these alternatives are developed and used. Other alternatives have shown positive test results but are not universally applicable. For instance, CO_2 pellet blasting for paint stripping works for some aircraft parts but causes substrate damage on certain aircraft (47).

Conclusion

The recent shift in focus from end-of-the-pipe pollution control to pollution prevention is necessary to deal with the environmental problems involved with managing hazardous waste. Pollution prevention is easier to implement when there is a cooperative effort among government, industry, and society. The EPA efforts involve setting effective policies, integrating cross-media pollution prevention into all EPA programs, and providing information that assists in effective pollution prevention implementation.

The AF plays a large role in ensuring pollution prevention success since preventing pollution at the source often involves manufacturing process or operation modifications.

III. Existing Cost-Benefit Evaluation Techniques

Introduction

There are many approaches to evaluate the economic feasibility of an alternative project. This thesis investigates the methodology of three cost models used to evaluate alternative environmental projects. These include the methodologies used by Ernst and Young, the EPA, and AFLC's pollution prevention programs.

Ernst and Young (40:917-933).

Ernst and Young developed a methodology to evaluate economic feasibility of environmental projects. This method may be used to evaluate the feasibility of practically any type of project.

Quantitative Elements. The method involves five categories of costs. These categories are direct manufacturing, indirect manufacturing, environmental, hidden environmental, and capital costs.

Direct manufacturing costs are those which can be physically associated with a finished product during the manufacture process. These costs consist of direct labor, supervisory labor, fringe benefits, operating supplies, utilities, overhead, and depreciation.

Costs associated with indirect manufacturing have no physical association with the finished product and include

indirect labor, indirect materials, tooling, machining, quality control, maintenance, scheduling, resource planning, and industrial engineering.

Environmental costs are indirect costs which include wages for material handlers, waste treatment operators, and environmental monitors. Costs for waste treatment and environmental facility supplies and hazardous waste disposal also fall into this category.

Hidden environmental costs include environmental notification, reporting, recordkeeping, manifesting, labeling, and monitoring. Costs for inspections, training, and insurance are also included.

Costs associated with new equipment, engineering, facility modifications, and materials are capital costs of waste minimization projects. Other capital costs include equipment permitting, training, and contingencies. Capital cost savings due to equipment salvage value are also a part of the analysis.

The Ernst and Young method consists of two approaches for comparing an existing process to an alternative: incremental cost analysis and total cost analysis.

Incremental cost analysis is convenient to use when the cost categories between the current process and the alternative are the same. For example, utility costs apply in both cases. In this situation, the Ernst and Young method considers only incremental changes in costs. The

incremental costs are converted to net present value (NPV) for the comparison.

Total cost analysis is appropriate in situations where the cost categories between the current process and the alternative do not match. For example, facility lives vary or equipment modification cost applies only to the alternative. In this case, the total costs of the current process and the alternative are calculated and converted to NPV before they are compared.

> The primary means of evaluating financial feasibility is the net present value of the project cash flows. The net present value calculation considers the time value of money by discounting the incremental cash flow to current dollars. (40:926)

The criteria for economic feasibility requires a positive NPV. Ernst and Young also recommends a sensitivity analysis to see how sensitive the decision is to changes in assumptions.

Indirect benefits are important to consider when evaluating the economic feasibility of alternative environmental projects. There are two types of indirect benefits. One is measurable and the other is difficult to quantify. Avoided costs and liabilities, such as disposal costs and fines, are indirect benefits which are quantifiable but sometimes difficult to predict with accuracy due to associated uncertainties. Indirect benefits which are not quantifiable include improved corporate image and better relations with the regulators. Estimates of these benefits are purely subjective.

Estimates of indirect benefits may be accomplished by probability analysis or by qualitative analysis of the NPV gap between the current process and the alternative.

Probability analysis is useful for estimating quantifiable benefits. Expected costs and times of occurrence are estimated from historical data. For example, past data on fine issuance can be used to predict future occurrences. The next step is to estimate the probability the event will occur. This probability is multiplied by the estimated cost to yield an expected monetary value (EMV). The EMV is converted to NPV for inclusion in the economic analysis. Ernst and Young recommends a sensitivity check on the probability analysis.

Qualitative Elements. Qualitative analysis of the NPV gap is a useful method of subjectively considering the impact of non-quantifiable indirect benefits. The NPV gap is the difference between the NPV of the current process and NPV of the alternative.

The first step in the qualitative analysis is to develop a list of non-quantifiable benefits. This list might include avoided bad press, good press, positive taxpayer/voter perceptions, improved public relations, and better relations with regulators. Each item in the list is evaluated and prioritized with a weighting factor based on the amount the item potentially contributes to the indirect benefits.

> For example, a process which eliminates a highly toxic and persistent waste has a greater potential for producing indirect benefits than a process which eliminates a less hazardous easily treated waste. (40:932)

The indirect benefits are compared to the NPV gap to determine if the potential contribution of the indirect benefits compensates for the NPV gap.

The Ernst and Young method of economic analysis of environmental project alternatives is the first method reviewed which describes a way to quantify indirect benefits.

EPA Guidance (22:19-23).

The EPA's "Waste Minimization Opportunity Assessment Manual" provides guidance to organizations for developing and implementing a waste minimization program. The economic evaluation guidance suggests that "standard measures of profitability" (e.g., internal rate of return, payback period, and NPV) are appropriate, however, it is up to the organization to select their own measure and set their own criteria for project selection.

The manual discusses a preliminary rather than detailed approach to economic analysis. The analysis is divided into two parts. The first part consists of a comprehensive break-down of capital investment costs for a waste minimization project. Operating costs and savings associated with waste minimization projects constitutes the second part.

Capital investment costs are sub-divided into direct, indirect, and working capital costs. Direct capital costs include site development, process and mechanical equipment, materials, utilities, construction, and installation. Indirect capital costs include costs related to in-house and contracted engineering, permitting, contractors' fees, start-ups, training, and contingencies. Working capital costs involve costs of raw materials and finished product inventories, materials, and supplies.

Savings associated with waste minimization include reduced costs for waste management, input materials, insurance, and liabilities. Consideration should also be given to changes in costs associated with utilities, operations, maintenance, and overhead. There may be changes in revenues from increased or decreased production and from the sale of by-products.

Economic feasibility of alternative projects is determined by evaluating the annual cash flows of the above costs. If the capital costs are minimal, project feasibility is based on the savings in operating costs. If the capital costs are high, the analysis is more involved due to evaluation of capital costs.

Payback period, internal rate of return (IRR), and NPV determine economic feasibility. The suggested feasibility criteria requires a payback period of not more than three to four years, an IRR of 12 to 15 percent, and a positive NPV.

The savings due to reduced risks are not directly included in the calculations of payback period, IRR, and NPV. The EPA method considers these savings by making the economic feasibility criteria less stringent. For example, the payback period might be increased or the IRR decreased. These adjustments are strictly judgmental and built subjectivity into the analysis.

The EPA recommends the evaluation include a sensitivity analysis. This type of analysis evaluates how sensitive a project's economic feasibility is to changes in variables such as disposal costs and interest rates.

The EPA also recommends the feasibility study include a separate discussion of intangibles such as liabilities and improved public image. These costs are strictly qualitative but are important to consider in the decision making process.

PACER REDUCE (34:47-59).

PACER REDUCE, the AFLC-originated waste minimization program, uses the benefit-cost analysis outlined in DOD regulation 7041.3 to justify waste minimization projects. The analyses are capable of evaluating single or multiple alternatives. The cost analysis follows AFR 178-8 for guidance on project life and sensitivity analysis.

The PACER REDUCE cost analysis calculates the benefits and costs of an alternative considering the time value of money and places the values in a benefit to cost ratio. The

criteria for an acceptable project requires the ratio of benefits to costs be greater than 1.0.

The PACER REDUCE program recognizes that long-term environmental liabilities should be considered in any cost analysis, however, the program views liabilities as too difficult to quantify and only gives them subjective consideration in the final decision.

Conclusion

The AF's success in preventing or minimizing pollution and reducing environmental management costs is contingent upon many factors. Implementing a pollution prevention project depends in part on its cost effectiveness when compared to pollution management. This chapter reviewed existing means of evaluating cost effectiveness of alternative projects.

IV. Pollution Prevention Investment Decision Model for Pollution Prevention Alternatives

Hazardous material use and waste generation are very costly Air Force activities in terms of dollars, liabilities, and risks to human health and the environment. One effective way to reduce these ever increasing costs is to implement pollution prevention technologies. These technologies reduce and sometimes eliminate hazardous material use and waste generation. The sooner environmental managers implement smart pollution prevention decisions, the quicker hazardous material and waste management costs will decrease. Consequently, environmental managers should expedite pollution prevention decisions. The Pollution Prevention Investment Decision Model (PPIDM) is a vehicle for quick decision-making. This model provides managers with simple, systematic, and flexible guidelines for decision-making involving pollution prevention alternatives. The model provides step-by-step procedures and rules-of-thumb which managers, faced with selecting optimal alternatives, will find useful in decision-making tasks of this nature.

There are several advantages to using the PPIDM. First, it allows environmental managers to make obvious decisions immediately. These circumstances occur when political considerations override economics, economic

benefits clearly exceed project feasibility criteria, or when the decision is to use resources smartly.

Where decisions are not obvious, the model requires minimal analysis necessary to evaluate project feasibility. As a worst case, the model requires an in-depth study on projects where top management's support for intangibles (e.g., press, public, and regulator relations and employee attitudes) is low and economic benefits are difficult to find.

Figure 4.1 illustrates a situation where an environmental manager has three projects to evaluate. In this scenario, the manager can only choose one project. All three projects yield comparable total economic savings over a specified time-frame, however, the savings occur at different times. Project A yields immediate savings, whereas projects B and C do not yield savings until the eighth and twelfth month respectively. In this situation, the environmental manager must weigh the advantages of the larger recurring savings of projects B and C with the disadvantage of continuing to expend valuable resources on hazardous waste management for the 8 or 12 months it takes to implement pollution prevention project B or C. Implementation of project A is a smart use of resources due to the immediate reduction in hazardous waste volumes and immediate economic savings as well. Sometimes it is better to do something now than to wait. This example illustrates

why environmental managers should focus their efforts on expediting implementation of pollution prevention projects.

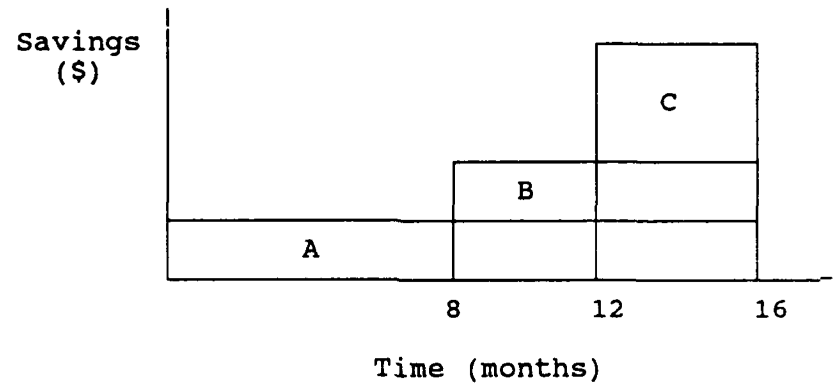

Figure 4.1 Savings Comparison of Three Pollution Prevention Projects

The major components of the PPIDM are the PPIDM equation, cost considerations, and the incremental approach. This section develops an understanding of the PPIDM components, provides a PPIDM decision map, and concludes with a description of the overall PPIDM decision flow process.

PPIDM Equation

Eq (4.1) is the PPIDM equation.

$$\text{PP Profits} = PP_B - PP_{CC} \qquad (4.1)$$

where

PP_B = Net Present Value of the annual Pollution Prevention Benefits (PP_{AB})

PP_{CC} = Pollution Prevention Capital Costs

The PPB term is found using Eq (4.2). This equation converts the pollution prevention annual benefits (PP_{AB}) to net present value (NPV) by multiplying the annual benefits by the equal payment series present worth factor (PWF) (27:45).

$$PP_B = PP_{AB} \times PWF \tag{4.2}$$

$$PP_B = PP_{AB} \times \frac{(1+i)^n - 1}{(1+i)^n}$$

Eq (4.2) takes a new form by substituting (E_b - E_a) for PP_{AB}.

$$PP_{CC} = (E_b - E_a) \times \frac{(1+i)^n - 1}{i(1+i)^n} \tag{4.3}$$

where

E_b = Annual expenses before Pollution Prevention
E_a = Annual expenses after Pollution Prevention
i' = Inflation free interest rate
n = equipment life in years

Eq (4.4) calculates the inflation free interest rate which is the market interest rate with inflation effects removed (27).

$$i' = \left(\frac{1+i}{1+f}\right) - 1 \tag{4.4}$$

where

i = market interest rate
f = inflation rate

PPB represents the total costs avoided or reduced as a result of implementing the pollution prevention alternative provided $E_b - E_a$ yields a positive value. PP_{cc} is the capital equipment investment cost which includes equipment, training, and installation.

Eq (4.1) is not the preferred method for evaluating projects since it requires the manager to calculate the inflation free interest rate, i′, which involves estimates of the market interest rate and inflation rate. This builds potential error into the analysis.

Manipulation of the PPIDM equation allows environmental managers to evaluate the financial feasibility of pollution prevention alternatives based on selected criteria which do not require interest rate assumptions. This research illustrates the use of two different feasibility criteria to increase the flexibility of the PPIDM. This provides managers with the option of selecting the criteria which best fits their particular needs. The two criteria are the popular rate of return (ROR) and payback period (56:1177).

Rate of Return. Rate of return (ROR) tells managers if their return on investment improves with expenditures of additional capital as a result of selecting one project over another. ROR is appropriate to use when there is only one alternative to evaluate. Incremental ROR is the best criteria for selecting a single project from a group of alternatives (19). It tells managers what percentage they are making on their investment as a result of selecting one

project over the next best alternative. ROR and Incremental ROR represent the interest rates which causes the present value of the pollution prevention capital investments to equal the present value of the annual pollution prevention benefits (56:1176). Eq (4.5) sets the present value of the capital investment equal to the present value of the annual benefits. Eq (4.6) solves for the PWF. The values for PP_{CC} and PP_{AB} are both known.

$$PP_{CC}=(E_a-E_b)\times PWF \tag{4.5}$$

$$PWF=\frac{PP_{CC}}{PP_{AB}} \tag{4.6}$$

Eq (4.7) represents the equal-payment series present worth factor. Solving Eq (4.7) for the interest rate gives the ROR or incremental ROR (27:45). The variable n is the assumed equipment life in years.

$$\frac{(1+i)^n-1}{(1+i)^n}=\frac{PP_{CC}}{PP_{AB}} \tag{4.7}$$

The ROR can also be found by using economic interest tables where the ROR corresponds to the present worth factor (See Eqs (4.6) and (4.7)) and assumed equipment life, n, in years. Interpolation between interest rates may be

necessary. Project feasibility requires the ROR to be greater than the minimum attractive rate of return (MARR). The Air Force MARR is 0.10 or 10 percent (54:29).

Payback Period. The payback period tells an environmental manager how long it takes for an investment to pay for itself. This research includes payback period as a feasibility criterion since the Air Force frequently uses it for project justification. The calculation is very simple and deserves little explanation. Eq (4.8) illustrates the payback period calculation (56:1169).

$$Payback = \frac{PP_{CC}}{PP_{AB}} \tag{4.8}$$

where

PP_{CC} = Pollution Prevention Capital Costs
PP_{AB} = Pollution Prevention Annual Benefits

Expense/Benefit Considerations

The objective of this PPIDM component is to make managers aware of the various decision factors to possibly consider during the project evaluation process. Table 4.1 provides expense/benefit considerations for managers to be aware of when evaluating the financial feasibility of pollution prevention alternatives. Every expense/benefit consideration may not be applicable in every situation. The environmental manager becomes knowledgeable of the process and its pollution prevention alternatives and determines

which considerations to include in their particular evaluation.

Incremental Approach

The incremental approach is the PPIDM component which saves time and enables managers to make quicker decisions. The speed of a decision is important because time saved translates to dollars saved. This approach divides the cost considerations into 3 different categories (see Table 4.1): intangibles (level 1), primary tangibles (level 2), and secondary tangibles (level 3). Ease of quantification and likelihood of data availability are the criteria for dividing the data into the 3 categories.

Dividing the data in three levels promotes efficient use of manager's time by eliminating any unnecessary steps in the project evaluation process. Spending time on project feasibility analysis is costly and time-consuming. A large number of considerations are necessary to conduct a full-scale feasibility analysis. A full-scale analysis is not necessary in every, or even most, situations and the PPIDM identifies these situations. The PPIDM incremental approach allows managers to evaluate alternatives by considering data one level at a time beginning with level 1 and proceeding to levels 2 and 3 only if necessary.

Projects which do not satisfy the manager's criteria for financial feasibility at level 2 must progress to the next higher level for additional data considerations.

Table 4.1 Cost Considerations by Level

Intangibles (Level 1)	Primary Tangibles (Level 2)	Secondary Tangibles (Level 3)
Improved Public Image Avoided Bad Press Enhanced Regulator Relations	Capital Costs - Equipment - Engineering - Installation - Training - Permitting - Facility and Utility Mods	Administrative Pollution Mgt - Permitting - Manifesting - Monitoring - Reporting - Recordkeeping - Contingency planning
Improved Employee Attitudes	Equipment Maintenance	Chemical Usage Training
	Raw Materials	
	Storage	Liabilities - Health Hazards -- Medical attention -- Time off work - Spills - Regulatory Fines and Penalties - Landfills
	Utilities - Water - Energy	
	Productivity - Manpower - Parts Throughput	
	Pollution Mgt - HW Disposal - End-of-the-pipe Treatment -- IWTP -- Air Control Equipment	
	Personal Protective Equipment (PPE)	

Level 1 Data. Level 1 contains intangible data which are difficult to quantify (e.g., public, press, and regulator relations, and employee attitudes). Evaluation at this level establishes the project economic feasibility criteria environmental managers require from level 2 and possibly level 3 analysis. Level 1 gives environmental managers the flexibility to adjust the standard economic

feasibility criteria depending on top management's and the public's value for level 1 considerations. High level 1 significance corresponds to less stringent economic feasibility criteria. If top management considers level 1 factors significant enough to completely override economic feasibility criteria, then the manager implements the project immediately. If not, the manager proceeds to level 2.

This approach assumes project funding approval is within the base-level environmental manager's control. However, if funding approval rests in the control of HQ USAF, adjustments to standard economic feasibility criteria may not be possible. In order to obtain HQ USAF approval, projects must show a 3 year or less payback or be efforts to reduce ozone depleting chemicals (18).

Level 2 Data. Level 2 data are easy to quantify and are likely readily available such as pollution prevention investment costs (e.g., equipment, engineering, installation, training, permitting, and facility and utility modifications), equipment maintenance, raw materials, storage, utilities, productivity, pollution management (e.g., hazardous waste disposal and end-of-pipe treatment), and personal protective equipment (PPE).

If the evaluation proceeds past level 1, the manager evaluates easily quantifiable data in prioritized increments and only performs the minimum analysis necessary to show economic feasibility. This approach is time-efficient since

most projects will show feasibility within level 2 and rarely require level 3 analysis. In circumstances where level 2 analysis does not reflect economic feasibility, the manager proceeds to level 3.

Since level 2 data contain all pollution prevention initial investment and operation and maintenance costs, it is safe to assume that progressing to level 3 analysis, which reflects net pollution prevention savings, will only strengthen the argument for the pollution prevention alternative.

Capital Equipment Costs. Capital equipment costs are one-time pollution prevention equipment investment costs which make up the PP_{cc} variable of Eq (4.5). Process engineers are excellent sources for this information, especially engineering hours and equipment permit requirements. Base civil engineering is a good source of information for facility and utility modification costs.

Annual Equipment Maintenance. This consideration contributes to both E_b and E_a values in Eq (4.5). Equipment maintenance personnel will be able to provide estimates for parts replacement frequency, parts costs, annual maintenance manhours, and average equipment maintenance personnel wage rates.

Raw Materials. Annual raw material costs may contribute to both E_b and E_a values in Eq (4.5). Supply personnel have access to raw material unit costs and process supervisors can provide estimates of raw material usage.

Storage. Quantification of storage costs is not always appropriate since existing storage space is a past investment or sunk cost. Storage costs are important considerations when implementation of a pollution prevention alternative eliminates the need to construct new storage space.

Utilities. Utility cost considerations may contribute to both E_b and E_a values. Base civil engineering will be able to provide utility unit costs, whereas process engineers and supervisors are good sources for usage estimates.

Productivity. It is difficult to place a monetary benefit on manhours saved as a result of changing from one process to another since employees are earning the same wages regardless. It is important, however, to estimate the value of additional throughput which results from the increased manpower efficiency. For example, the Air Force may consider the value of increased aircraft throughput in a maintenance facility as improving national defense.

Pollution Management. Pollution management costs will likely yield both E_b and E_a values. Environmental managers track hazardous waste disposal volumes and costs handled by both base contractors and the Defense Reutilization and Marketing Office (DRMO). End-of-pipe treatment of wastes are significant considerations, such as waste processing through industrial waste water treatment plants (IWTPs).

Maintenance of existing air emission control equipment and costs of new air emission controls projected for installation to meet new environmental laws are extremely significant considerations. Equipment maintenance personnel and process engineers are knowledgeable of maintenance costs and new emission control equipment costs respectively. The Environmental Protection Agency (EPA) is also an excellent source of information regarding new air emission control equipment costs.

Sunk costs such as existing control equipment are not considerations in this type of analysis. Projected equipment or construction costs avoided as a result of implementing a pollution prevention project are important considerations. These costs are actually negative E_a values.

Personal Protective Equipment (PPE). Evaluate PPE considerations for E_b and E_a values. Supply personnel track costs of PPE and process supervisors are aware of replacement frequency. Other considerations include manhours expended on annual respirator fit tests and annual maintenance on dedicated air compressor equipment. Base level bioenvironmental engineers and equipment maintenance personnel provide this data.

Level 3 Data. Data in level 3 are not as readily available and are more difficult to quantify. Level 3 data include administrative pollution management costs (e.g., permitting, manifesting, monitoring, reporting,

recordkeeping, contingency planning, and storing), chemical usage training, and liabilities (e.g., health hazards, spills, regulatory fines and penalties, and landfills).

Environmental managers may only be able to estimate level 3 considerations (e.g., liabilities) using some type of probability analysis. This type of analysis is especially time-consuming; therefore, it is critical the manager evaluate only the data increments necessary to show economic feasibility.

Administrative Pollution Management Costs. Evaluate administrative pollution management considerations such as permitting, manifesting, monitoring, reporting, recordkeeping, contingency planning, and training for both E_b and E_a values. Environmental managers can provide estimates of the time dedicated to each of these activities. Time employees spend away from normal duty equates to productivity loss. This type of loss to the Air Force could adversely impact national defense levels or decrease aircraft throughput in a maintenance facility. Individual organizations may accomplish hazardous material training for risks unique to their particular process. In these situations, process supervisors can provide estimates of training manhours.

Chemical Usage Training. Employees who use hazardous chemicals to perform their jobs, must take initial hazardous chemical training as well as annual refresher courses. The time employees spend away from work

accomplishing training requirements is significant when the number of employees who handle hazardous chemicals is large. This time away from normal duty equates to productivity loss.

Liabilities. The importance of liability considerations can not be understated due to the potential significance of these costs. Liability considerations include health hazards, spills, landfills, and regulatory fines and penalties which all yield E_b and E_a values.

Health Hazards. Evaluation of health hazards involves estimates for medical attention and time off work resulting from worker injury directly or indirectly attributable to hazardous materials or wastes. It is difficult to obtain costs for medication and treatment since this would require inquiry into individual medical insurance documentation in addition to interviews with all injured personnel. However; estimates are possible to account for lost worker manhours due to medical appointments and duty restrictions by reviewing organizational medical records. Once the annual number of worker injuries is known, it is possible to estimate medical attention costs by assessing medical professional wages and associated manhours expended for processing injured workers. This technique does not include all costs of health liabilities; however, it does provide an estimate of the minimum costs. These costs will only increase with time.

Spills. Evaluation of spill liabilities involves probability analysis. One method involves developing a spill frequency distribution for spills associated with a particular process. Table 4.2 provides an example.

Table 4.2 Sample Historical Monthly Spill Occurrences

Spills per month	Frequency of Occurrence
0	1
1	2
2	4
3	3
4	1
5	1
	12

Conversion of this data to a probability distribution is possible by dividing the spill observation frequency by the total number of cbservations. Table 4.3 provides the probability distribution for the data in Table 4.2.

Figure 4.3 Spill Probabilities

Spills per month	Probability of Occurrence
0	1/12 = .08
1	2/12 = .17
2	4/12 = .34
3	3/12 = .25
4	1/12 = .08
5	1/12 = .08
	12/12 = 1.00

Computation of the expected number of spills per month is the accumulated product of the number of spills and the probability of occurrence. Eq (4.9) demonstrates this computation.

$$\begin{aligned} \text{Expected spills} &= \Sigma \text{ Spill probability X Spills} \qquad (4.9) \\ &= (.08)(0) + (.17)(1) + (.34)(2) \\ &\quad + (.25)(3) + (.08)(4) + (.08)(5) \\ &= 2.32 \text{ spills/month} \\ &= 28 \text{ spills/year} \end{aligned}$$

The next task is to estimate the average cost per spill. Consider only the most recent annual spill cost data since improvements in spill clean-up technologies and efficiencies are resulting in lower clean-up costs. Consideration of extensive historical clean-up costs could result in large estimate error. The intent is to make a reasonable and conservative estimate and avoid reflection of worst-case and best-case spill scenarios.

Data for estimating individual spill clean-up costs includes manhours expended by all personnel responding to the spill, contractor costs, equipment use, raw material use, lost throughput, and overhead costs. Multiply the average cost per spill by the expected number of spills per year to estimate the annual spill clean-up costs.

Landfills. Landfill liability is an extremely significant consideration. This subject is the focus of an entire doctoral dissertation by Captain James Aldrich, AFIT PhD student at the University of Cincinnati (1).

This research develops a method to predict the long-term liabilities of landfilling hazardous wastes. The method relates landfill failure to landfill liner failure and uses expected value analysis to calculate the cost of landfill failure (1:43). The expected value of landfill failure is the product of the probability the failure will occur and the cost of hazardous waste destruction (per unit basis) (1:54). Once a landfill liner fails, destruction or relocation of the hazardous waste in the landfill is necessary. This research uses the term waste destruction to represent this cost. Eq (4.10) represents the total cost of landfill liabilities (1:63).

$$P_t = P_l + f_L(P_d) \tag{4.10}$$

where

P_t = Total landfill liability cost ($/unit)
P_l = Cost of landfilling hazardous wastes ($/unit)
f_l = Liability factor
P_d = Hazardous waste destruction cost ($/unit)

These procedures require calculating the liability factor, f_l, by summing the product of the yearly present value factors and the associated expected value factors over the landfill age (1:59). This is actually the "total percentage of the destruction cost that should be added to the landfill cost to represent the total cost of landfilling the waste..." (1:59).

Regulatory Fines and Penalties. Similar to spills, environmental managers may use probability analysis to estimate the expected costs of fines and penalties.

PPIDM Decision Map

Figure 4.2 is the PPIDM decision map for evaluating a single pollution prevention alternative.

Decision Flow Process

This section describes step-by-step procedures for environmental managers to follow to evaluate the feasibility of a single pollution prevention alternative.

Step 1. Identify the process. The EPA establishes a list of priority hazardous and toxic chemicals which drives the selection of processes to receive consideration for pollution prevention technologies. Processes which use chemicals on the priority list are targets for pollution prevention.

Step 2. Identify the pollution prevention alternative. Sources of information regarding pollution prevention technologies include the EPA's Pollution Prevention Information Clearinghouse, commercial industry, annual Air Force pollution prevention conferences, Air Force research laboratories at Tyndall AFB, and university research.

Step 3. Become familiar with the entire process and identify every input and output associated with both the original process and the pollution prevention alternative.

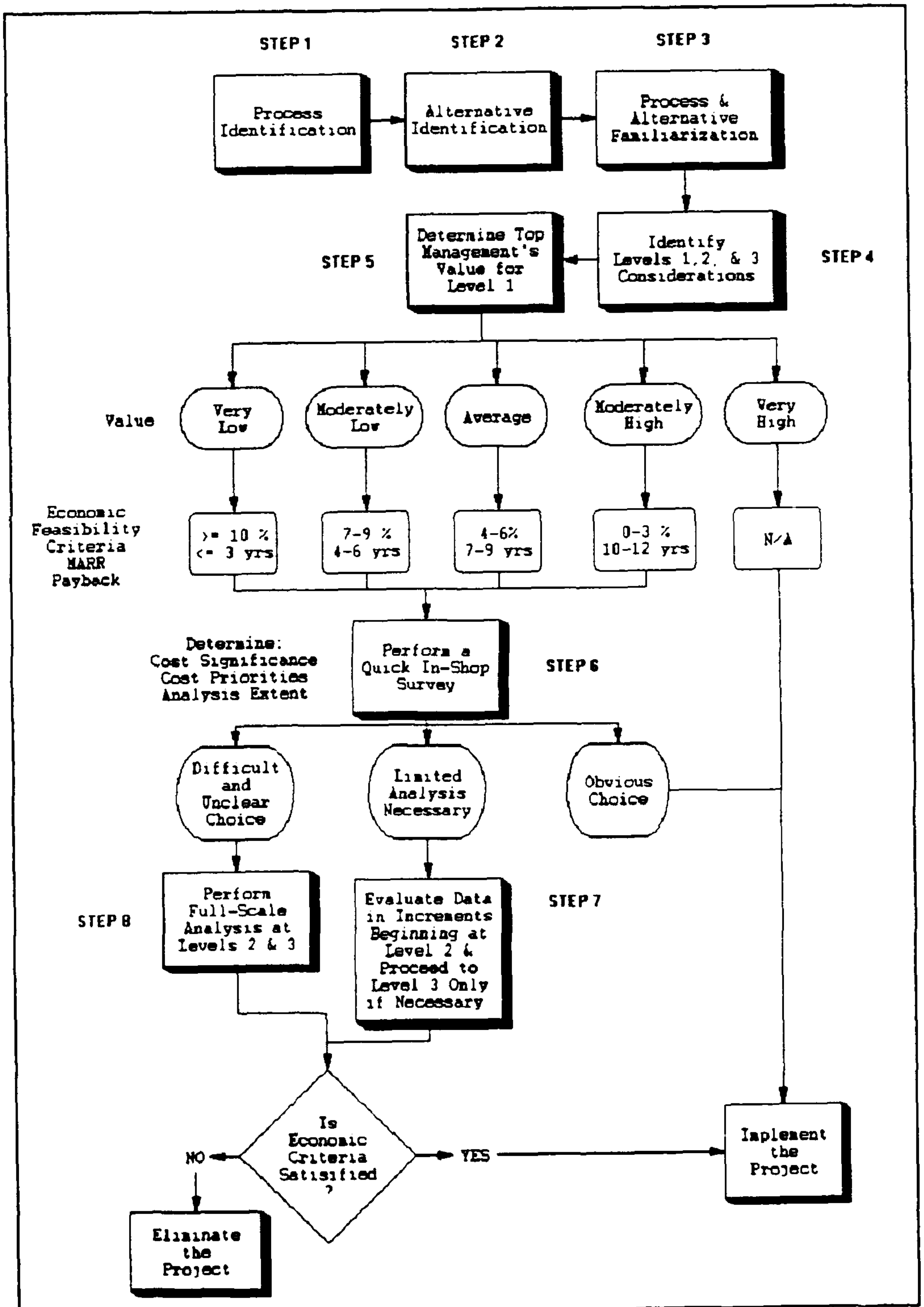

Figure 4.2 PPIDM Decision Map for Assessing a Pollution Prevention Alternative

Be aware of any impacts on the process from the external environment such as new laws and regulations.

Step 4. Identify the considerations associated with all inputs and outputs and categorize these considerations as intangibles (level 1), primary tangibles (level 2), and secondary tangibles (level 3).

Step 5. Determine the value of top management's support for level 1 considerations. The measure of value is made by leadership's interpretation of local politics, efforts to improve public image, avoid bad press, enhance regulator relations, or just to establish environmental policy. Based on this value, the environmental manager adjusts the required economic feasibility criteria in accordance with Figure 4.3. Figure 4.3 is a graduated scale which provides rules-of-thumb relating economic feasibility criteria to the value top management places on level 1 considerations.

Where level 1 importance is very low, the project must stand on economics alone; however, where level 1 importance is very high, subjective considerations completely override the importance of economics and the manager implements the project immediately. Moderately high, average, and moderately low level 1 ratings also qualify for reductions in feasibility criteria requirements.

Step 6. Perform a quick in-shop (versus field) survey to determine the significance of level 2 and 3 costs,

MARR (%)	≥ 10	7-9	4-6	0-3	NA
Payback (yrs)	≤ 3	4-6	7-9	10-12	NA
Level 1 Importance	Very Low	Moderately Low	Average	Moderately High	Very High

Figure 4.3 Graduated Scale for Adjusting Economic Feasibility Criteria

prioritize the pollution prevention costs within each level, and determine the extent of the analysis necessary to achieve project feasibility criteria. Environmental managers should not collect cost data which is older than one year. If average historical costs are based on data for the past 5 years, the costs could contain significant error. The most accurate data will be the average annual costs for the last year. This technique reflects the impacts of current laws and regulations and any other external environmental factors.

When it is obvious the project benefits satisfy the economic feasibility criteria without further evaluation, implement the project.

Step 7. If the quick in-shop survey reveals only a limited analysis is necessary, quantify and evaluate the minimum data increments necessary to reach the project feasibility criteria beginning with level 2 and proceeding to level 3 if essential. Environmental managers must include all PP_{CC} and pollution prevention equipment maintenance and operational costs in every analysis. Once the analysis satisfies the feasibility criteria, implement

the project. If the analysis fails to achieve feasibility, eliminate the project.

Step 8. If the project benefits are unclear following the in-shop survey, perform a full-scale analysis involving all data levels. If this analysis meets the feasibility criteria, implement the project. If the analysis does not meet the criteria, eliminate the project.

Summary

This research develops an investment decision model which allows environmental managers to make quicker decisions on choosing pollution prevention alternatives to pollution management. The model encourages an awareness of all cost considerations in the decision-making process and describes a procedure for evaluating alternatives on an incremental basis (3-level approach) depending on incremental ROR or payback feasibility criteria. The PPIDM gives managers a new and flexible method of adjusting economic feasibility criteria according to the significance of intangibles such as political considerations. Finally, it offers environmental managers a method to estimate liabilities such as spills and regulatory fines and penalties using probability analysis.

The incremental approach is very time efficient since it requires only the minimal analysis necessary to achieve project feasibility. Projects which satisfy the feasibility criteria at level 1 qualify for immediate implementation.

Most projects proceeding past level 1 will satisfy economic criteria through savings in level 2 costs alone (e.g., raw materials or hazardous waste disposal). This eliminates the need to proceed to the next level of analysis. Managers include level 3 data for any projects having feasibility deficiency following level 2 evaluation and for projects competing for economic resources. This approach to project feasibility analysis provides managers with a way to make potentially quicker decisions without sacrificing accuracy. Quicker decisions saves valuable time which translates to valuable resources.

V. Pollution Prevention Investment Decision Model: Multiple Pollution Prevention Alternatives

The procedure for selecting a single project from a group of alternatives to pollution management differs from the procedure for deciding on a single pollution prevention alternative to pollution management. The difference is significant and deserves to be addressed separately. This chapter provides a PPIDM decision map for more than one pollution prevention alternative and describes the differences from single alternative analysis.

PPIDM Decision Map

Figure 5.1 is the decision map which outlines the process an environmental manager follows when assessing a project from more than one alternative.

Decision Flow Process

The first five steps of the decision process for choosing among multiple pollution prevention alternatives are identical to the steps in the previous chapter. This section begins with step 6 where the two processes begin to differ.

Step 6. Perform a quick in-shop survey to determine if one of the projects is obviously more feasible than the others and satisfies the feasibility criteria without further evaluation. When this occurs, implement the project immediately. Managers must keep Figure 4.1 in mind when

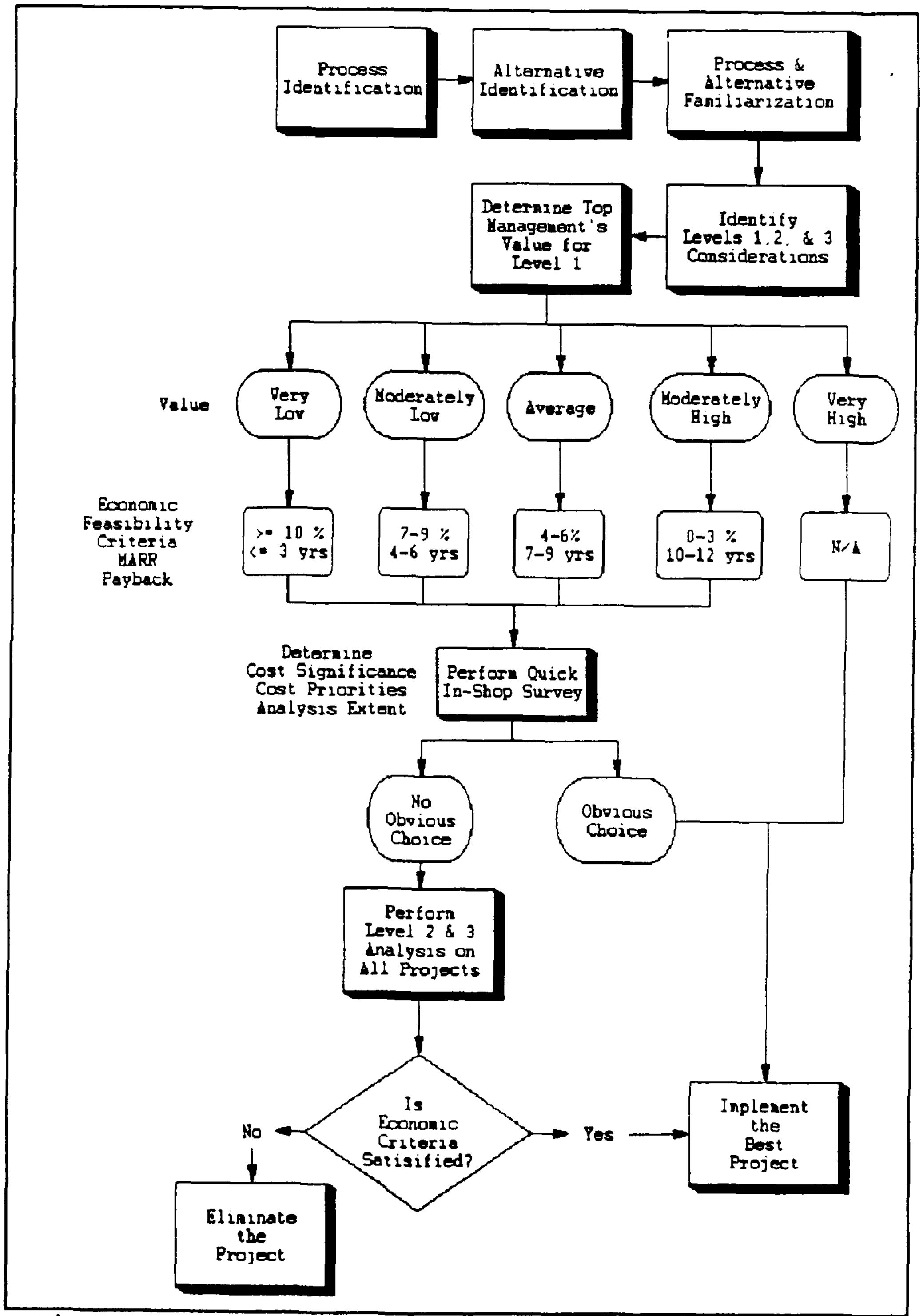

Figure 5.1 PPIDM Decision Map for Assessing Multiple Alternatives

evaluating multiple projects. If the quick in-shop survey reveals all projects economically comparable and the projects have different start dates, then it is smart use of resources to choose the project which has the soonest start date. In this scenario, managers should expedite projects which yield immediate savings with the intention of switching to more cost-effective technologies when they become available. Where there is no obvious selection, proceed to step 7.

Step 7. Quantify level 2 and 3 cost considerations. The fact that there are multiple pollution prevention alternatives establishes the need to include all quantifiable (level 2 and 3) cost considerations in the initial feasibility evaluation. All pollution prevention capital and operation and maintenance costs are in level 2; therefore, proceeding to level 3 is to the benefit of all pollution prevention projects. The significance of this benefit is unknown and varies from alternative to alternative; consequently, it is necessary to evaluate all alternatives at levels 2 and 3.

Step 8. Evaluate the pollution prevention alternatives based on the project feasibility criteria. Once all values for PP_{cc}, E_b, and E_a are quantified for level 2 and 3 considerations, project feasibility calculations are possible. Payback period calculations are the same as described by Eq (4.8); however, the incremental ROR analysis requires additional steps when evaluating multiple

alternatives. An incremental rate of return is necessary to calculate among all alternatives. Incremental rate of return tells environmental managers how much they are making on their investment by choosing to implement a particular project over the next best alternative (27:86). The following example illustrates the process of selecting the project which yields the best rate of return among several projects.

Consider the projects and associated capital and annual costs in Table 5.1. This example assumes a 10 year (n = 10) equipment life for all projects.

Table 5.1 Sample Data for Incremental ROR Analysis Among Multiple Projects

	Hazardous Waste Process Project A	Pollution Prevention Project B	Pollution Prevention Project C	Pollution Prevention Project D
Capital Costs ($)	0	60,000	70,000	90,000
Annual Costs ($)	22,000	14,230	9,611	3,000

The first step in a rate of return analysis of multiple projects is to arrange the projects in order of increasing capital costs (27:87). The next step is to calculate the incremental rate of return between Project A and Project B. This calculation is possible using Eqs (4.6) and (4.7) from

the previous chapter. This section repeats these equations for convenience.

$$PWF=\frac{PP_{CC}}{PP_{AB}} \tag{4.6}$$

$$\frac{(1+i)^{n}-1}{i(1+i)^{n}}=\frac{PP_{CC}}{PP_{AB}} \tag{4.7}$$

The present worth factor is 60,000/7770 or 7.722. Solving Eq (4.7) for i yields the incremental ROR. The incremental ROR can also be found by using economic interest tables where the incremental ROR is the interest rate which corresponds to the present worth factor (Eq (4.6)) and the equipment life, n, in years. The percentage which corresponds to a present worth factor of 7.722 and an equipment life of 10 years is 5 percent. Five percent is the rate of return as a result of choosing Project B over Project A. Since 5 percent is below the government MARR of 10 percent, Project B is eliminated.

Now the evaluation is between Project A and Project C. The present worth factor is 70,000/12,389 or 5.650. The percentage which corresponds to a present worth factor of 5.650 and an equipment life of 10 years is 12 percent. This is greater than the government MARR of 10 percent; therefore, Project A is eliminated.

The analysis is now between Project C and Project D. Project D is eliminated by observation since the difference in annual costs gives a negative number and is, therefore, not a benefit.

Project C is the most economically feasible project in this example. If no project satisfies acceptable economic feasibility criteria, the analysis proceeds to level 3 analysis.

Summary

This chapter provides a PPIDM decision map and outlines the procedure for environmental managers to follow when choosing among multiple pollution prevention alternatives to pollution management. The process is significantly different than that for a single pollution prevention alternative. The differences are the need to consider both level 2 and 3 cost considerations in the economic evaluation and the requirement to perform an incremental rate of return analysis among all projects.

VI. Cost Model Illustration Using Depainting Hangar Systems Operations Case Study

Introduction

This case study implements the PPIDM using the Tinker AFB depainting systems operation as a case study illustration. Use of this operation as the case study is based on the recent initiatives taken by the facility production engineers to phase out use of toxic solvents. It is not the intent to promote specific pollution prevention technologies, but rather provide managers with a comprehensive sample-run to illustrate the parts of the PPIDM model application. In this case, only proven depainting technologies which have been fully developed and successfully tested for their intended purposes are evaluated.

The following model illustration takes on an overall "systems" approach to cost-benefit analysis. Entire facility inputs and outputs are evaluated since the facility is completely dedicated to a single process. The decision-maker can easily use the PPIDM on the changes in inputs and outputs from the facility. Although the cost considerations in the following example are numerous and varied, they are not necessarily all appropriate for every cost analysis application. The comprehensive nature of this example should illustrate how various decision factors are important when considering pollution prevention alternatives.

Process Description

The system chosen for evaluation herein involves the aircraft depainting operation taking place in Facility 2122, Tinker Air Force Base, Oklahoma. This particular aircraft hangar provides paint stripping services to KC-135s, large aerial refueling tanker aircraft, and B-52Gs, large wingspan 1960 vintage bombers. Stripping of the aircraft surface area takes place in large bays on either end of the hangar. Cleaning and stripping of aircraft component parts takes place in the middle bay of this hangar. Aircraft component parts consist of line generated items and Maintenance Items Subject to Repair (MISTR). Line generated items are parts taken from the aircraft which are tagged when removed. These parts are placed back onto the aircraft once serviced. MISTR parts are those which come from the established supply system (13). Figure 6.1 provides a Process Flow Diagram depicting the system orientation.

Previous Stripping Methods. Historically, all three bays used methylene chloride and phenol based solvents to strip and clean the aircraft and the parts. These previous chemical strippers are extremely toxic and acutely hazardous to the workers when inhaled or in contact with the skin. These two chemicals are among the hazardous chemicals targeted for removal by both Tinker and the federal regulators (45:5).

Use of these chemicals to strip the aircraft and components to bare metal requires several applications of

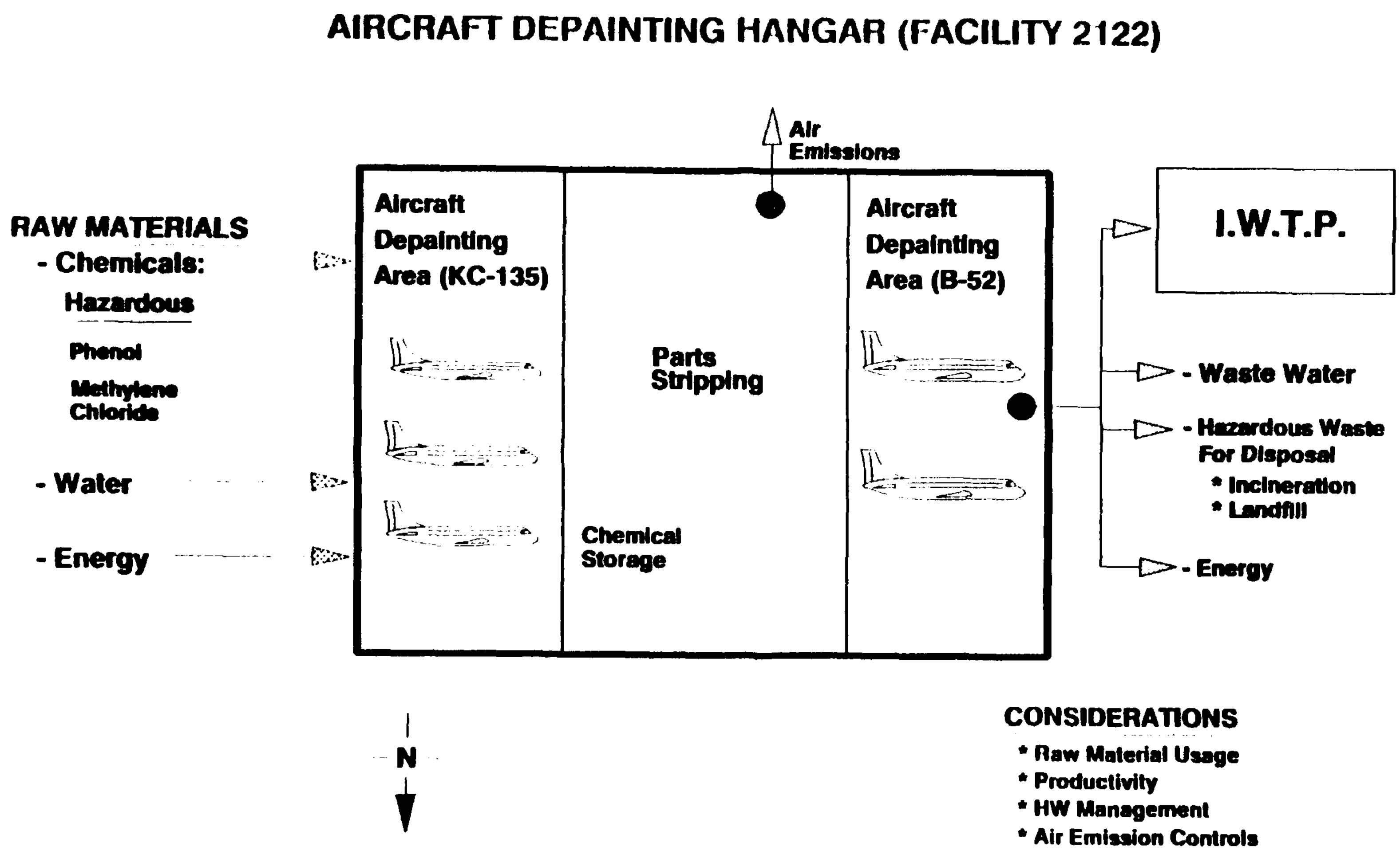

Figure 6.1 Pollution Management Process Flow Diagram

each chemical solution. The raw stripping agents were all stored in the middle bay area. French style floor drains collected used solvent and wastewater runoff and discharged them to the industrial wastewater treatment plant (IWTP). A contractor usually monthly removed sludge (paint chips, dirt, and chemical residue) accumulations from these drains and disposed of it as hazardous waste.

Use of methylene chloride and phenol based solvents generated significant quantities of hazardous waste, as well as large quantities of wastewater for treatment in the base's IWTP (45:5). Additionally, worker conditions were far less than ideal, with frequent incidents of worker exposure requiring medical attention. The hazardous nature of this work required personnel to be fully suited in protective clothing with a fresh air breathing system. The protective clothing is extremely uncomfortable in the high temperatures common in Oklahoma in the summer months.

Prior to the 1990 Clean Air Act Amendments (CAAA), Oklahoma air quality standards placed the state in "attainment" status (i.e., air quality is within standards). With this qualification, there were no emission control requirements on building 2122. Building 2122 could legally and routinely emit substantial volumes of the volatile organic compounds (VOCs) from the stripping solvents. Tinker AFB neither treats nor permits with the state regulatory agency its air emissions from this facility (48).

Depainting System Background for Case Study

The facility 2122 production engineers have been actively pursuing pollution prevention alternative depainting technologies. As a result of their efforts, four new alternatives are either in place or planned for this facility.

Recently, one new pollution prevention alternative, benzyl alcohol based solvent, replaced in part the traditional use of toxic solvent. Benzyl alcohol is non-hazardous and is a typical chemical-base found in perfumes, deodorants and baby lotion (45:1). The trade name for this benzyl alcohol stripping solvent is SR-125A, Polysulfide Remover. This solvent is applied directly to the entire aircraft.

Since 1989, the second pollution prevention alternative, plastic media blasting (PMB), has been in operation. This operation also replaces the previous use of the toxic solvents. The media, in the form of small beads, is blown under high pressure to strip major aircraft components.

A third new alternative, carbon dioxide (CO_2) blasting, is in place but is not fully in operation. The CO_2 blasting will be used strictly for cleaning grit and grease from line generated aircraft parts. The methylene chloride and phenol based solvents are currently used for this purpose.

A fourth new technology, a Large Aircraft Robotic Paint Stripping (LARPS) system, is projected for operation by

1995. This system will strip the aircraft using high-pressure water, which is fully recycled. System developers expect it will take only half the time to strip an aircraft, while reducing hazardous waste generation by ninety percent (7:21).

The full implementation of these four new pollution prevention processes in this facility will essentially eliminate air emissions and reduce generation of hazardous waste and wastewater to a fraction of what it was previously. This also relieves workers of the exposure hazards, and consequently, most of the requirements for personal protective equipment are eliminated. Until implementation of the LARPS, small quantities of methylene chloride and phenol will remain in use for aircraft paint stripping. However, once the LARPS is in operation, there will no longer be a need for these solvents. Figure 6.2 depicts these four process modifications.

Benzyl Alcohol Alternative Physical Analysis. Currently, the benzyl alcohol based solvent process strips aircraft exterior surfaces in the east bay area. "The new process requires no new equipment investment and no increase in aircraft flow times" (45:5). The time to process an aircraft through this facility is routinely five days (48). Although this throughput rate has not changed from the traditional method, the actual manhours spent on this process, as well as raw chemical usage, has substantially decreased.

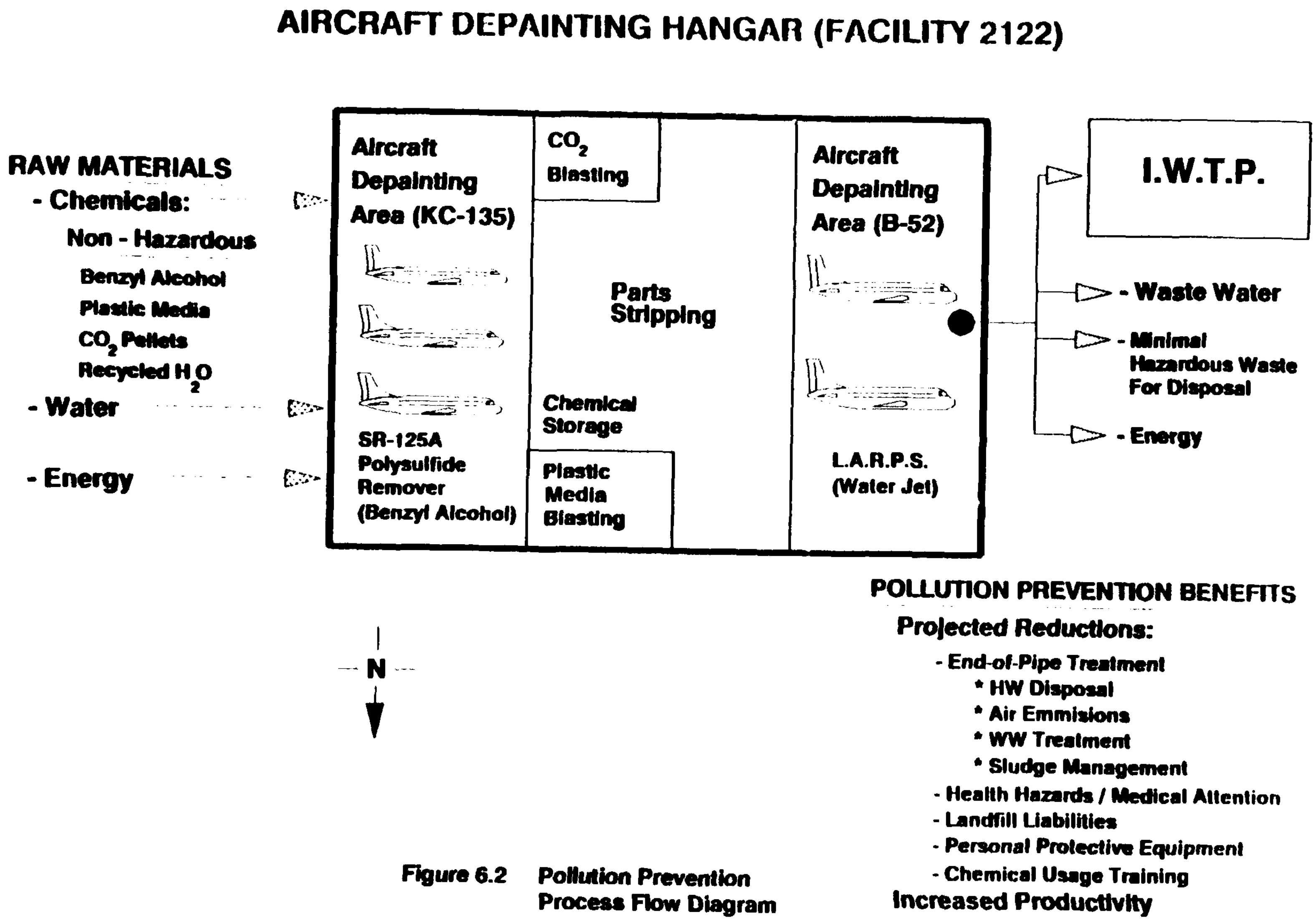

Figure 6.2 Pollution Prevention Process Flow Diagram

With this new process, approximately half as much chemical as was previously used is applied to the aircraft and allowed to sit for several hours. During this dwell time, manhours can be productively applied elsewhere in the hangar. Once adequate buckling of the paint has taken place, a squeegee wipes off the chemical, paint and primer. Reapplication of benzyl alcohol is not necessary. With this process, there is less volume in paint chip and chemical residue sludges and the sludge can be disposed of far more cheaply. In fact, according to EM personnel, initial laboratory analyses indicate the cost of the benzyl alcohol sludge disposal will be approximately seventy-five percent lower than the former sludge material (42). Table 6.1 lists the cost considerations associated with this new process.

Plastic Media Blasting Physical Analysis. Plastic media blasting of large aircraft parts take place in the middle bay area. The parts are paint stripped using plastic media in a small blasting booth. This process requires special blasting equipment. PMB blasting produces plastic and paint chip waste but in much smaller waste volumes and at a cheaper disposal cost than the original process. The plastic beads are separated and reused up to fifteen times until they become fine dust. At this point the dust is disposed of with the paint chips as hazardous waste.

CO2 Blasting Physical Analysis. CO_2 blasting of aircraft parts takes place in the middle bay area. This is also done in a small blasting booth using CO_2 pellets for

Table 6.1 Case Study Cost Considerations

Intangibles (Level 1)	Primary Tangibles (Level 2)	Secondary Tangibles (Level 3)
Improved Public Image Avoided Bad Press Enhanced Regulator Relations Improved Employee Attitudes	Capital Costs - Equipment - Engineering - Installation - Training - Permitting - Facility and Utility Mods Equipment Maintenance Raw Materials Storage Utilities - Water - Energy Productivity - Manpower - Parts Throughput Pollution Mgt - HW Disposal - End-of-the-pipe Treatment -- IWTP -- Air Control Equipment Personal Protective Equipment (PPE)	Administrative Pollution Mgt - Permitting - Manifesting - Monitoring - Reporting - Recordkeeping - Contingency planning Chemical Usage Training Liabilities - Health Hazards -- Medical attention -- Time off work - Spills - Regulatory Fines and Penalties - Landfills

cleaning. Although high pressure frozen CO_2 pellet blasting requires special equipment, and therefore, up-front cost, the only wastes generated are the paint chips and grit falling from the part. The CO_2 pellets are made from CO_2

removed from the air and frozen. The CO_2 fully sublimes once it hits the part and is therefore returned to the atmosphere.

Table 6.1 also lists the cost considerations associated with these two processes. Because these blasting booths are located against the side walls, whereas the old chemical process took place in the middle of the bay, these new processes allow far more space for storage (i.e., plastic media, benzyl alcohol, and aircraft parts), as well as open space, lending to good housekeeping practices.

LARPS. No further information is available on this system at this point in time. Hence, the LARPS will not be considered any further in this analysis.

Because less chemical is used, these new processes improve the overall cleanliness of the building and reduce the potential for hazardous chemical spills. In addition, the processes remove paint better than the traditional method, without increasing process time. In fact, the productivity of workers actually increases in some instances. Direct costs and benefits associated with these pollution prevention processes are not the only considerations evaluated in this sample model application. The model also accounts for improved worker attitude, safety and health and avoided medical attention, projected 1990 CAAA impact avoidances, and any further reduced environmental regulatory compliance requirements.

The following section provides details on raw material usage and waste generation.

Cost Factors and Pollution Prevention Analysis

External factors (e.g., new laws and regulations) can prevent historical data from holding any true predictable relationship with time. Consequently, only most current data accurately reflect situations now and in the future. Historical data is generally not kept readily accessible due to lack of routine automation in the past. Therefore, this data collection would be extremely difficult, if not impossible, under these circumstances. This case study exercise revealed the fact that collecting historical data (e.g., over the past five years) is not feasible nor necessary. Rather, evaluation of data for a "snapshot" in time makes an effective and efficient decision.

Data Collection and Manipulation. Data collection took place at Tinker AFB during the week of 22 June 1992. The following discussion details the methods for data collection and manipulation. It also discusses any assumptions made during the evaluation process. The order for discussion here parallels the order of the cost category considerations in the PPIDM leveled approach (reference Chapters III and IV). The appendix lists the raw data and shows the data manipulations necessary to convert it all to common units (e.g., \$/yr for annual costs). This data reflects CY91 costs unless otherwise specified.

Intangibles. Included in the intangible considerations (level 1) are improved public image, improved worker attitude, avoided bad press, and enhanced regulator relations. These are subjective considerations and are not quantifiable. This case study assigns a value, based on an interview with the production engineer, from the Likert scale established in Chapter IV of this document (see Figure 4.2). The production engineer considered both improved public image and worker attitude as very high in importance, and avoided bad press and enhanced regulator relations as moderately high in importance (48). These considerations, of course, are only applicable to the pollution prevention alternatives.

Primary Tangibles. The tangibles (level 2 considerations) applicable to this case study are capital costs, raw materials, utilities, manpower, pollution management, and personal protective equipment, excluding sunk costs. This research considers storage as a sunk cost, and therefore, does not include it in the analysis. The sections below describe the data collection and calculation processes.

Capital Costs. The facility production engineers provided costs of capital improvements to the thesis team (13; 48). Process equipment procurement, installation and any associated training costs were included in the contracts for the PMB and CO_2 blasting equipment. Expected equipment costs were in FY88 and 90 dollars,

respectively. Equipment life for the plastic media and CO_2 blasters is ten years (13). The costs of engineering and facility modifications for electrical runs are engineering estimates. There was also a yearly rental cost associated with the CO_2 blaster. These costs are not applicable to the benzyl alcohol application, as there is no new equipment involvement.

Raw Materials. The organizational supply personnel provided costs for the raw materials per fifty-five gallon drum (12). The depainting process supervisor provided the current (FY92) solvent usage rates shown in Table 6.2 (29).

Table 6.2 Raw Material Usage

	DCM Process drums/aircraft	Phenol Process drums/aircraft	PMB Process lbs/aircraft	CO2 Process	SR-125A Process drums/aircraft
Aircraft					
KC-135	12	13	N/A	N/A	12
B-52	14	16	N/A	N/A	17
Components					
Line-generate					
KC-135	2	2	285	N/A	2
B-52	1.5	1.5	195	N/A	1
MISTR Items	0.5 drums/wk	0.5 drums/wk	45 lbs/wk	N/A	.3 drums/wk

This data are broken out by solvent specific usage for each aircraft, their respective line-generated components, and the MISTR components. The old process uses two types of phenol and methylene chloride mixtures. The first, referred to as DCM in the data tables, contains eighty percent methylene chloride (also called dichloromethane). The second mixture, referred to as phenol, is sixty percent dichloromethane (13).

The production engineer provided usage rate and equipment efficiency for the CO_2 blaster and estimated the plastic media usage to be ninety-five percent of the plastic waste generated (13). To give a more accurate prediction of plastic media usage, the actual CY91 waste disposal database (see the 'Hazardous Waste Disposal' section below) amount was used versus the estimates provided in Table 6.2. The PMB equipment has a recycle rate of five to ten percent; therefore, process engineers estimate that the plastic media recycles up to fifteen times (13).

Since the data contained in Table 6.2 are current, they do not reflect the amounts of the toxic solvents (phenol/methylene chloride) used before the PMB process implementation. The process supervisor estimates a twenty-five percent reduction in usage of these solvents for stripping of all component parts (29). Therefore, these volumes are multiplied by four-thirds in the data manipulations to add back in that amount of solvents used before the pollution prevention alternatives.

Utilities. The facility production engineers provided the PMB and CO_2 equipment usage rates and power consumption, as well as the electricity cost at Tinker AFB (48). Raw water consumption is irrelevant since there is no cost associated with water supply from their own wells. The electricity cost for pumping water is assumed to be negligible. There are no utility costs associated with solvent application for either the old or the new methods.

Manpower. Current (FY92) manpower data was broken out by aircraft (i.e., KC-135 or B-52) and their respective line-generated components and MISTR components. The process supervisor provided this information, listed in Table 6.3, based on many years of supervisory experience (29). Aircraft throughput, obtained from the FY93 work schedule, is 37 KC-135s and 14 B-52Gs per year. This case study assumes a 50-week (250-day) year, taking into consideration time lost for holidays. Average supervisory and laborer wage rates (including overhead) gives a labor rate estimate of $19 per hour for use in the cost calculations.

Again, the current data does not reflect manpower quantities prior to PMB implementation. Here, the process supervisor estimated a two-thirds reduction in manpower dedicated to component parts (29). The data calculations thus multiply the manpower amounts for the PMB process by three and add this amount to the current manpower amounts for the old stripping process provided in Table 6.3.

Table 6.3 Manhours

	DCM/Phenol Process MH	PMB Process MH	CO2 Process MH	SR-125A Process MH
Aircraft				
KC-135	1040	N/A	N/A	860
B-52	950	N/A	N/A	802
Components				
Line-generated				
KC-135	363	36	N/A	300
B-52	150	16	N/A	128
MISTR Items	75	8	N/A	40

Pollution Management. Data included in pollution management for this process are hazardous waste disposal and end-of-pipe treatment such as wastewater treatment and future requirements for air emission controls.

Hazardous Waste Disposal. In this evaluation, generated hazardous waste requiring off-base disposal includes paint chip sludge from both the old and new processes, and used plastic media. A CY91 database printout, provided by EMC laboratory personnel, yielded quantities of waste plastic media generated during CY91 (39). The cost for plastic media disposal varies depending on the metal content from the paint. The database indicated

a range anywhere from \$0.38 to \$2.35 per pound (lb) in rare circumstances, but most typically it cost less than \$1.00. This case study uses \$1.00 per lb as a conservative estimate in the calculations. It should be noted that conversations with EMCO personnel revealed that DRMO is working toward selling this plastic waste to companies interested in the recycle value (17). This could corvert the disposal costs to profits in the future.

EMC personnel provided a disposal cost of \$1.48 per lb for the phenol/methylene chloride contaminated sludge (17). The CY91 database (referred to above) confirmed this to be the actual disposal cost. A discrepancy in sludge quantity exists however. The database showed a quantity of 79,250 lbs, whereas EMC and the depainting organization personnel indicated that 250,000 lbs was a reasonable estimate. The calculations herein assume 150,000 lbs of sludge generation as a conservative estimate.

Actual sludge disposal data following the benzyl alcohol solvent implementation in this facility (April 1992) was not available in time for this research. However, with the reduction in phenol and chromate content in the sludge, EMC personnel estimate that sludge disposal costs will decrease by seventy-five percent (42). With less chemical usage, sludge volumes should decrease. Since this data is not available, it is conservative to use the same quantity (i.e., 150,000 lbs) of sludge for post-benzyl alcohol implementation.

Wastewater Treatment. The depainting process supervisor estimated raw water usage per aircraft and aircraft component parts, including MISTR items (29). Table 6.4 lists this data. This made it possible to predict the amount of wastewater sent to the IWTP. Here, the process supervisor estimates a fifty percent reduction in water usage for component part stripping since implementation of the PMB process (29). Therefore, those usage amounts for component parts provided in Table 6.4 are multiplied by two in the data calculations. Again, the model assumes the data apply to a 50-week year.

Table 6.4 Water Usage

	DCM/Phenol Process gal/aircraft	PMB Process	CO2 Process	SR-125A Process gal/aircraft
Aircraft				
KC-135	45,000	N/A	N/A	30,000
B-52	50,000	N/A	N/A	35,000
Components				
Line-generated				
KC-135	38,250	N/A	N/A	25,500
B-52	42,500	N/A	N/A	29,750
MISTR Items	20,000 gal/day	N/A	N/A	10,000 gal/day

A production engineer for this facility indicated that a certain amount of the raw water is disposed of with the sludge as opposed to being sent to the IWTP (8). In this case, 50 percent of the sludge is water initially. The sludge disposal contractor then dewaters the sludge another ten percent before removing it from the base for disposal. Therefore, case study calculations add ten percent to the final sludge weight of 150,000 lbs and then subtract forty percent of that total. The following equation demonstrates this calculation:

$$S_d + 0.1*S_d = swbd \qquad (6.1)$$
$$W_s = 0.4*swbd \qquad (6.2)$$

where, S_d = drummed sludge weight for disposal
swbd = sludge weight before dewatering
W_s = water weight disposed of with sludge

This is the amount of water by weight removed with the sludge, and therefore, not sent to the IWTP. In other words, after compiling the raw water usage data, this amount of water is subtracted out to give the final volume requiring IWTP treatment. Water loss from evaporation is negligible. The model uses an estimated cost of $5 per 1000 gallons water for IWTP treatment expenses (11). As can be seen in Table 6.4, the benzyl alcohol process significantly reduces raw water usage.

Air Emissions. As explained in an earlier section of this chapter, the depainting process does not require air emission controls. However, with the new CAAA, a need for control equipment is expected for the

methylene chloride emissions in the future. This qualifies as a cost avoidance since Tinker AFB expects to eliminate the methylene chloride based solvent before the CAAA requirements become enforceable.

In calculating the process air inventories for documentation purposes, the production engineer uses an estimate of seventy-five percent vaporization of the methylene chloride content in the solvents (13). Since the depainting facility uses high volumes of solvents, this vaporization rate amounts to a significant contaminant load to the atmosphere.

To estimate the cost for procuring emission control equipment, pneumatic load from the facility is necessary. Per consultation with the HVAC personnel from the Civil Engineering Squadron, the maximum pneumatic load per exhaust fan for this facility is 110,000 cubic feet per minute (cfm) and there are a total of ten exhaust fans for the three bay areas (35). This amounts to a total of 1,100,000 cfm in a worst case scenario for this facility. Designing air emission control equipment to treat the worst case scenario load is a sound engineering practice (15).

Research into treatment equipment cost estimates led to discussions with an EPA expert in emission control equipment. The consensus between this EPA representative and the facility production engineers is that carbon adsorption is the best treatment technology for methylene chloride emissions (15; 48). The other treatment methods,

catalytic incineration and thermal incineration, are not appropriate in this case. For catalytic incineration, the chlorine destroys the catalyst. And in thermal incineration, free chlorine reacts with both the moisture in the air and the moisture produced from the burning and creates an acid, which is not acceptable (15).

For carbon adsorption, the cheapest of the technologies, the EPA representative quoted a capital equipment cost of $30 to $50 per cfm (15). This case study uses the average of $40 per cfm. For the 1,100,000 cfm load from this facility, the estimated cost for carbon adsorption equipment would therefore be $44,000,000. However, a smart manager would recommend a value engineering study to find acceptable ways to reduce this cost while still meeting all requirements. Due to the absence of design specifications, this study excludes annual maintenance costs for the treatment unit, which are typically quite high (36). This provides justification for including the high capital cost estimate. Although this cost reflects current year dollars, the cost avoidance does not apply until 1995 when implementation of the LARPS will phase out the DCM and phenol in entirety.

Personal Protective Equipment. Organizational supply personnel provided these costs for any equipment requiring replacement routinely (12). The capital costs of one-time equipment procurement are sunk costs, and are therefore ignored. Assumptions made here include a

labor rate of $30 per hour for fresh air assembly equipment maintenance. Filter changeouts require six maintenance hours, as well as do compressor media changeouts. Facility maintenance personnel estimate quarterly compressor filter changeouts and annual compressor media changeouts for each of three total compressors (4; 31).

Other assumptions include replacement rates of one shroud per day, one long breathing hose (from the individual to the fresh air compressor unit) per year, one cooling assembly per year, and one heating assembly per year (12). Thirty-nine workers require these replacements since twenty-eight employees work days and eleven employees work nights. Also, thirty-nine employees replace face respirator filters once a day at two filters per respirator.

To consider the cost of spectacle kits and starter kits for new employees, a turnover rate of ten percent is assumed for the facility. This is a conservative estimate considering the number of employees relocated or sitting at home due to chemical related medical problems (29). Additionally, the calculations assume fifty percent of the total fifty-eight employees wear glasses (6).

Per suggestion by the process engineer, this case study assumes a fifty percent decrease in the total cost for personal protective equipment for the pollution prevention alternatives (48). Again, this is conservative, considering more than fifty percent elimination of the toxic chemical use.

Secondary Tangibles. Included in the secondary tangible (level three) costs for this case study are chemical usage training and health hazard liabilities only. Administrative pollution management expenses are irrelevant, and therefore are not a part of this analysis, since they are essentially the same before and after implementation of the pollution prevention alternatives. In this case, spills are not significant since the process and chemical storage is all inside the facility. This case study neglects spill prevention since it is a sunk cost. Since Tinker AFB has never received fines from the regulatory agencies, costs of regulatory fines and penalties are not applicable.

Unfortunately, this research does not address landfill liability expenses due to time and data collection limitations. They are however relevant and significant. There is a method available to quantify the cost of landfill liability. For further explanation of this procedure, see the section on landfill liabilities in Chapter IV (Eq (4.10)) of this document.

Chemical Usage Training. The process supervisor provided the information for this category of costs (29). Included herein are the costs related to shop safety training (12 hrs/yr), hazardous chemical refreshers (8 hrs/yr), respirator fit tests (4 hrs/yr), and annual physicals (8 hrs/yr). A total of sixty-eight people work in this facility at an average labor rate of $19 per hour. Also, a ten percent turnover rate requires additional

training for seven employees. These calculations again assume a fifty percent reduction in the total training cost after implementation of the pollution prevention alternatives.

Health Hazards. Included in this category are costs of medical attention provided to the employees and the cost for any resulting time off work. Medical personnel provided this data for the CY91 period (6). This information includes those medical visits strictly related to the toxic chemical solvents (e.g., chemical burns or headaches resulting from fumes).

This data also includes time off work resulting from other medical problems that prohibited the use of personal protective equipment. An example would be if the worker had an upper respiratory infection and could not wear the fresh air breathing unit. These costs are included since the pollution prevention alternatives are expected to eliminate in part the need for personal protective equipment. Formal testing is currently underway to establish as fact that the benzyl alcohol is not hazardous to the employees (48). Once these testing results are documented, the need for fresh air breathing units or respirators will be eliminated and other personal protective equipment requirements will be reduced.

Medical Attention. This analysis assumes that fifty percent of the total visits are doctor only visits, twenty-five percent are nurse only visits, and twenty-five percent are nurse and doctor visits (6). Each

visit is approximately fifteen minutes in duration. An average labor rate for the doctor is $21.10 per hour (GS-12, step 5) or $5.25 per fifteen minute visit. The average labor rate for the nurse is $14.55 per hour (GS-9, step 5) or $3.65 per visit.

There were eighty-eight total documented visits relating to the chemicals or the personal protective equipment for the CY91 period (6). The model calculations apply doctors wages to fifty percent or forty-four visits, and nurses wages to twenty-five percent or twenty-two visits. Doctors and nurses wages apply to the other twenty-five percent or twenty-two visits. The total expense for this representative year was $500, which is fairly insignificant but is a consideration nonetheless. This evaluation provides a very low estimate, based on the process supervisor's statement that, on the average, five workers per day go to the medical center (29). In addition, this research does not include medical claims external to the AF due to data non-availability. Tinker AFB does not compile this data by organization and data automation was only very recently implemented.

Here, the calculations assume a seventy-five percent cost reduction after implementation of the pollution prevention alternatives.

Time Off Work. The total documented lost manhours for the year was 2610 (6). The data manipulation here is a multiplication of this number by the

Expected equipment costs were in FY88 and 90 dollars,

6-12

average labor rate of $19 per hour giving a total of $49,590 for the year. Again, this is a conservative estimate since claims were not included in the evaluation. The process supervisor estimates that four workers are on limited duty at any one time, which totals to 8000 hours lost per year (29). To illustrate the significance of medically related time off work, assuming an average of 5000 lost manhours, throughput would increase by approximately three and one half KC-135 aircraft per year (using Table 6.3 manhour data) without lost manhours.

Again, twenty-five percent of this total is estimated as the cost after implementation of the pollution prevention alternatives.

<u>Final Data</u>. Tables 6.5, 6.6, and 6.7 present the final data in CY92 dollars. This case study uses an inflation rate of five percent to adjust prior years dollars to current year dollars. These tables include data for only the benzyl alcohol (SR-125A) and PMB processes versus the methylene chloride and phenol process. The CO_2 process unfortunately is not included in this case study model application due to incomplete available data.

Table 6.5 lists the results for the intangible (level 1) considerations. These assigned numbers are based on a scale of one to five, from very low to very high degree of importance (see Appendix).

Table 6.5 Results: Intangibles

	DCM/PHENOL	PMB//SR-125A
	E(before)	E(after)
INTANGIBLES		
Improved Public Image	NA	5
Improved Worker Attitude	NA	5
Avoided Bad Press	NA	4
Enhanced Regulator Relations	NA	4
AVERAGE		4.5

The cost considerations within levels 2 and 3 have been placed in a prioritized order, according to cost significance. The costs for the benzyl alcohol and PMB processes are added together to represent costs after pollution prevention implementation on a "systems" basis. E(before) and E(after) represent expenses before and after pollution prevention implementation, respectively.

Table 6.6 lists the final results for the primary tangible (level 2) considerations. Itemized capital costs are considered first and a total capital cost is provided. The annual costs are then listed in a prioritized order for consideration. This is appropriate if the incremental approach for analysis is to be used. A total annual cost is provided for each process as well as for the difference before and after pollution prevention implementation. The annual savings at this level of consideration is $130,340.

Table 6.6 Final Data: Primary Tangibles

PRIMARY TANGIBLES	DCM/PHENOL E(before)	PMB/SR-125A E(after)	E(before) - E(after)
Capital Costs			
Process Equipment & Training	$0.00	$90,301.00	($90,301.00)
Installation	$0.00	$42,386.00	($42,386.00)
Engineering	$0.00	$1,751.00	($1,751.00)
Equipment Rental	$0.00	$0.00	$0.00
Facility & Utility Modifications	$0.00	$3,000.00	($3,000.00)
TOTAL CAPITAL COSTS		$137,438.00	($137,438.00)
Raw Materials	$552,755.00	$1,030,840.00	($478,085.00)
Productivity			
Manpower			
KC-135			
Aircraft	$731,120.00	$605,580.00	$125,540.00
Components	$331,113.00	$236,208.00	$94,905.00
B-52			
Aircraft	$252,700.00	$213,332.00	$39,368.00
Components	$52,668.00	$38,304.00	$14,364.00
MISTR	$94,050.00	$45,600.00	$48,450.00
Pollution Management			
HW Disposal			
Paint Chip Sludge	$233,100.00	$58,275.00	$174,825.00
Plastic/Acrylic Media	NA	$25,641.00	($25,641.00)
End-Of-Pipe Treatment			
Wastewater to IWTP	$85,677.00	$28,318.00	$57,359.00
Air Emissions	$44,000,000.00	NA	
Personal Protective Equipment	$159,425.00	$79,710.00	$79,715.00
Utilities			
Electric	$0.00	$460.00	($460.00)
Water	$0.00	$0.00	$0.00
TOTAL ANNUAL COSTS	$2,492,608.00	$2,362,268.00	$130,340.00

Lastly, Table 6.7 are the results for the secondary tangible data. Here again, data are in a prioritized order and a total annual cost is provided. Annual savings at this level is $58,239.

Table 6.7 Final Results: Secondary Tangibles

	DCM/PHENOL	PMB/SR-125A	
	E(before)	E(after)	E(before)-E(after)
SECONDARY TANGIBLES			
Liabilities			
Health Hazards			
Medical Attention	$500.00	$125.00	$375.00
Time Off Work	$49,590.00	$12,400.00	$37,190.00
Spills	NA	NA	
Regulatory Fines and Penalties	NA	NA	
Landfills	Missing	Missing	
Chemical Usage Training	$41,344.00	$20,670.00	$20,674.00
Pollution Management (Administrative)	NA	NA	
TOTAL ANNUAL COSTS	$91,434.00	$33,195.00	$58,239.00

PPIDM Application. Following is a discussion of the execution of each step of the PPIDM for this case study data.

Steps 1 Through 3 Evaluation. Tinker AFB fulfilled steps one through three of the PPIDM (reference the decision flow process section in Chapter IV) prior to the initiation of this case study. Identification of this process was based on the EPA's and Tinker AFB's mutual desire to eliminate the use of methylene chloride and phenol based chemicals. The four new pollution prevention processes described herein were the identified alternatives. As stated earlier, these processes were previously tested and fully developed for their intended purposes.

Step 4 Evaluation. A previous section of this chapter discusses step 4. All cost considerations

applicable to this case study were categorized by the three level criteria and are presented in Table 6.1.

Step 5 Evaluation. In determining the economic feasibility criteria, top management's subjective view of the political climate evaluated the need for pollution prevention alternatives to be moderately to very high in importance, a score of 4.5 on the Likert scale (reference Figure 4.3). This corresponds with a conservative MARR of zero to three percent and a payback of ten to twelve years (reference Figure 4.2). In other words, the subjective considerations for this particular case minimizes the importance of economics. In this case, Tinker AFB bypassed the remaining economic portion of the assessment and began the implementation of the alternative processes.

Steps 6 Through 8 Evaluation. A quick in-shop survey would indicate that a limited economic analysis was necessary. Hence the remaining analysis which follows is more in depth than is actually necessary. This detailed analysis is included to illustrate the formulation and refine the PPIDM development. It also demonstrates the benefits gained from the pollution prevention alternatives. The following sections are the economic assessment according to step 7 procedures which include a full-scale analysis of levels 2 and 3 data.

Level 2. The tabulated costs included in Table 6.6 are summed for the DCM/phenol and PMB/SR-125A columns respectively. At level two the capital cost for

PMB/SR-125A is $137,438. The annual costs are $2,492,608 per year for DCM/phenol and $2,362,268 per year for PMB/SR-125A, amounting to an expected annual benefit of $130,340 for the new processes. Payback is simply the capital costs divided by the annual benefits as follows:

$$Payback = \frac{PP_{CC}}{PP_{AB}} \tag{6.3}$$

$$Payback = \frac{\$137,438}{\$130,340} = 1.05 years$$

ROR is calculated using equation 4.3 and solving for the interest rate. Equipment life, n, is ten years. Inserting the actual case-study values gives:

$$PP_{CC} = (E_b - E_a) \times \frac{(1+i)^n - 1}{i(1+i)^n} \tag{6.4}$$

$$\$137,438 = (\$130,340) \times \frac{(1+i)^{10} - 1}{i(1+i)^{10}}$$

$$i = 0.95$$

In this case the ROR is 95 percent. Both feasibility criteria exceed the acceptable criteria (payback of ten to twelve years and ROR of zero to three percent) by a substantial margin. Here, it is not necessary to proceed to the level 3 cost considerations since this evaluation indicates economic feasibility for the pollution prevention

alternatives solely on level two calculations. Again, level 3 is evaluated to illustrate data quantification.

Level 3. Level 3 data is considered to assess any additional benefits of the pollution prevention system. The total for the E(before)-E(after) column data of Table 6.7 is necessary here. At this level of data consideration, the added annual benefit of the new processes is $58,239 which brings total savings to $188,579. Including this in the economic analysis gives a new payback of 0.73 years and a ROR of 137 percent.

This analysis did not consider the future avoided cost of air emission control equipment. This is because true avoidance cannot be guaranteed until the use of methylene chloride and phenol are fully eliminated. This will occur with final implementation of CO_2 blasting and the LARPS. Since this case study PPIDM application only considers two of the four alternatives, including the full cost avoidance would not be valid. To include this cost consideration, an assumption of the percent of the full savings attributed to the PMB and SR-125A could be made. As seen from the high capital cost of this control equipment (forty-four million dollars), consideration of even a portion of this cost avoidance would have made a substantial impact in the overall evaluation. Inclusion of avoided landfill liabilities would make the SR-125A process even more attractive in terms of annual benefits.

Conclusion

This case study demonstrates the use of the PPIDM to evaluate the economic feasibility for pollution prevention processes. In this case, the payback period and ROR greatly exceed both the AF acceptable criteria of three years and ten percent, respectively, and the adjusted level 1 criteria of ten to twelve years and zero to three percent. Management support is critical in order to implement pollution prevention project(s). In this case study, top-level management subjectively rates these projects very high in importance, and therefore, required economic criteria are reduced considerably.

At an annual benefit of $130,340, delaying the decision to implement these projects would cost $521 per day, or $65 per hour[1]. This illustrates the significance of the need for managers to make quick decisions.

[1] assuming a 250 day year and eight hour workday

VII. PPIDM Benefits and Future Insights

Introduction

This chapter briefly summarizes the research effort and describes the original and unique features of the PPIDM. Insights gained while performing the research, and particularly the case study, are also discussed. Last, it includes recommendations for future research.

Research Summary

This research examines the problem of pollution management as a costly and risky business, particularly within the Air Force. It then explores the possibilities for replacing current pollution management policies with a pollution prevention direction. The research emphasizes the need to acquire top-level management support of pollution prevention activities at a particular installation. To be attractive, pollution prevention alternatives must be cost-effective.

The primary objective in this research was to develop a pollution prevention investment decision model (PPIDM) for managers' use in evaluating the financial feasibility of pollution prevention alternatives in lieu of continuing to manage pollution. The model uses an incremental approach to evaluate data in three levels. The first level consists of subjective (intangible) considerations by upper management and is the basis for establishing the economic criteria for

the subsequent cost/benefit assessment. Level 2 includes primary tangible recurring cost considerations and all pollution prevention initial investment and operation and maintenance costs. Level 3 analysis quantifies secondary data which only increases pollution prevention savings. Since level 2 contains all pollution prevention initial and operation and maintenance costs, level 3 analysis is only necessary if level 2 did not satisfy the economic criteria established at level 1. Level 3 data will always yield net benefits for the pollution prevention alternative.

This research applies the PPIDM in a case study involving aircraft depainting operations. This case study is comprehensive and illustrates the use of the PPIDM. It also demonstrates the benefits that can be realized through pollution prevention.

PPIDM Benefits

The PPIDM effectively provides managers with simple, systematic, and flexible guidelines for making accurate and expedient decisions when considering pollution prevention alternatives. The model discourages spending unnecessary time in the evaluation process and establishes procedures to avoid comprehensive analyses where unnecessary. It gives managers the flexibility to make adjustments to the economic criteria based on top management's perceptions of the political environment. The PPIDM also helps the decision maker to consider the most significant factors first and to

make the decision as soon as the alternative appears financially feasible. The following sections further discuss the unique attributes of the PPIDM.

Emphasis on Expedient Evaluations. As stated above, the PPIDM emphasizes the need for urgency in pollution prevention alternative evaluations. The model guidelines facilitate quick, yet effective, choices. Expediency is important since the quicker a cost-effective alternative is implemented, the sooner cost savings will be experienced. Often, economics are not the most important considerations. In these situations, the importance is placed on reducing volumes of hazardous wastes/materials as soon as possible without concern for profitability. Unnecessary time spent by managers in making a decision is an unnecessary expenditure of both human and monetary resources.

Adjustments to Economic Criteria. Economics are not the only consideration in evaluating pollution prevention alternatives. In fact, economics are not always the most important. How management perceives the implications of improved public image, worker attitude, regulator relations, and bad press should determine the importance of profitability. Economics are unimportant in situations where management's value for subjective considerations is very high. Therefore, feasibility evaluations should address subjective considerations first. Economic criteria should then be adjusted to reflect management's perceptions of the political environment. The model provides a Likert

scale of economic criteria adjustments based on how important subjective considerations are, on a case specific basis.

It is important to be aware that no matter how sensitive management is to political issues, Air Staff will only fund pollution prevention projects which meet specific economic criteria. For this reason, management should be prepared to commit funds from alternative sources, if necessary, in order to implement a politically important project.

Incremental Approach. Once the economic criteria is established, the PPIDM emphasizes the importance of data prioritization within each level of cost considerations. The prioritization begins with the data collection process. The key is to first collect costs which have the greatest impacts. Pollution prevention capital costs and annual operation and maintenance costs must be considered in every analysis. The analysis then incorporates costs which result in the greatest savings comparatively between projects.

The evaluation proceeds in an incremental fashion, descending down the prioritized list until the established economic criteria are met. This approach saves decision making time and shows that a comprehensive analysis is not necessary in most situations.

Quantification of Spill Liabilities. The PPIDM provides guidelines for estimating spill liabilities. This same procedure may also be used for estimating regulatory

fines and penalties. These are significant considerations and should be considered in all pollution prevention alternative evaluations. In the past, most economic evaluations did not address liabilities. The guidelines offered by the PPIDM are easy to follow; therefore, managers will be more likely to include these considerations in the evaluation process.

Stepped Evaluation Process. The PPIDM approach is broken down into clearly defined steps much like any problem solving process. This characteristic makes the PPIDM systematic with procedures that any manager should be familiar with. Thus evaluating pollution prevention alternatives with the PPIDM should quickly become a routine for the decision maker.

Insights Gained

Significant insight was gained through this research process. The following discussion describes the revelations experienced while executing the case study.

Data Relevance and Availability. It was discovered that it is not important, or even appropriate, to collect extensive historical cost data. The potential volatility of external factors prevent data from holding any true predictable relationship with time. Examples would be the affects of promulgation of new regulations or discovery of a new, more efficient remediation technology.

Documented historical data are very limited, and that which is documénted is maintained in largely inaccessible paper files. The Air Force is beginning to compile and track environmental and health-related data with new data automation systems. This will greatly improve data accuracy and accessibility.

The most important insight regarding historical data collection contradicts traditional belief that the more data the better. When collecting historical cost data for environmental projects, it is important to remember the most accurate costs are those spent or saved today and in the future.

It is common to encounter situations where data are not available. In such cases, knowledgeable process supervisors can provide estimates which are likely as accurate as data which is documented.

Case Study PPIDM Application. Research methods requires methodology development prior to actual research. It became very evident that the case study actually guided the reformulation and refinement of the decision model (methodology). There is definitely a feedback loop acting in every research process. Figure 7.1 depicts this phenomenon.

The case study was a very important factor in development of a practical model. Had the case study not been accomplished, the model would possibly be unusable in practical applications.

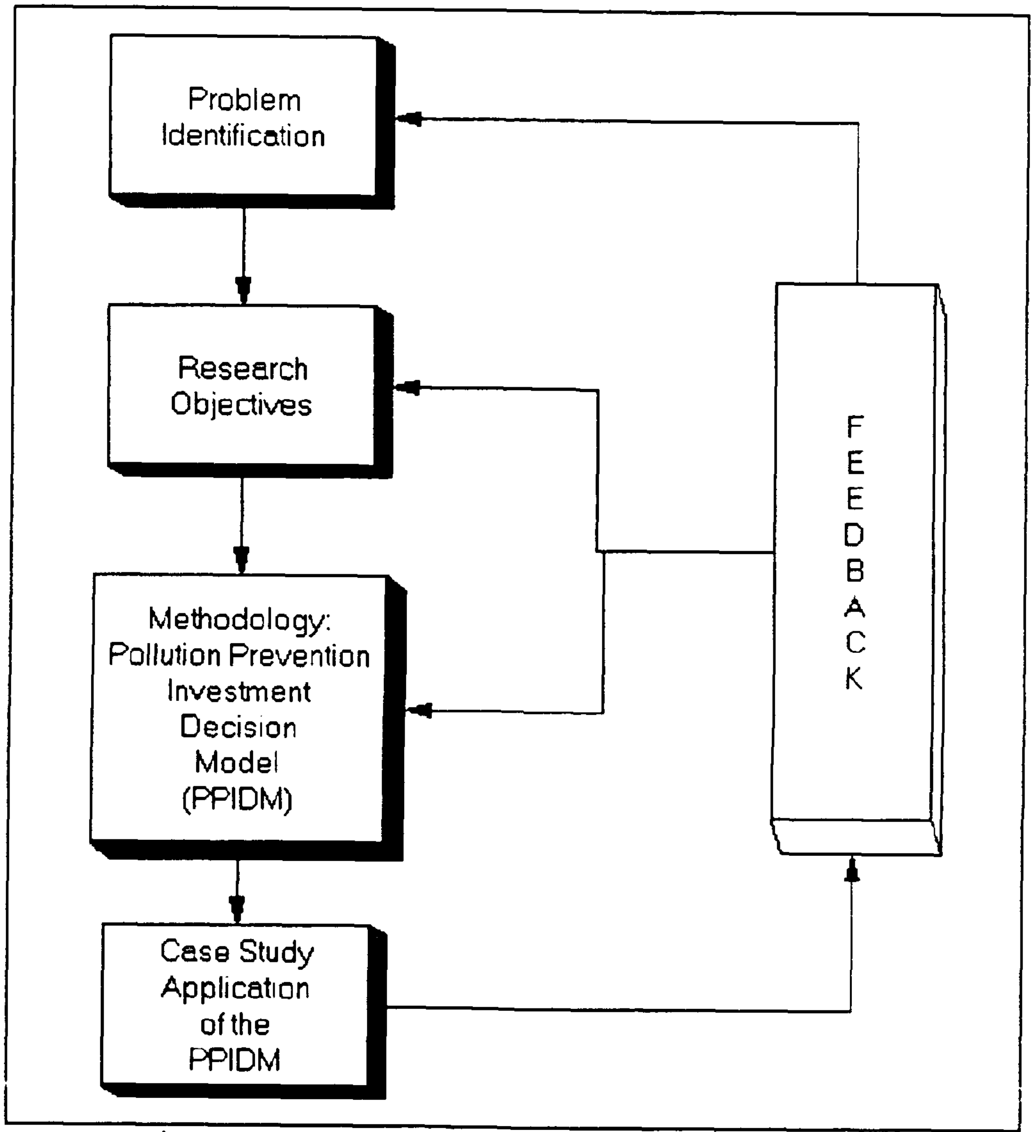

Figure 7.1 Research Process Feedback Loop

Unfortunately, this case study PPIDM application does not accurately reflect the true cost savings experienced. Certain significant data could not be accurately quantified (e.g., health risk and landfill liability expenses), and several assumptions and estimations were built in. Also,

missing data prevented the inclusion of two future processes in the case study analysis.

Much of the cost data in this case study is more accurate than what would be available in an actual project feasibility study since the case study technologies analyzed were already in operation.

The Big Picture. This case study is a successful demonstration of how significant pollution prevention alternatives can be in terms of both economics and political factors. The depainting operation, however, is only one small part of an entire process. Incorporation of pollution prevention should begin in the acquisition process - in this case, aircraft coating and paint selection. The acquisition process should ensure that any paints purchased can be removed with non-hazardous chemicals. Environmental concerns should be an integral part of every aspect of the acquisition process. Engineers and managers need to step back and look at the whole system in order to find the most efficient and effective problem solutions.

Need for Cultural Change. After reviewing the case study results, the obvious question is: "Why has it taken so long to discover and implement these new depainting technologies?". The answer is "political and organizational inertia". There is desperate need for a cultural change, to incorporate pollution prevention into organizational mindsets from top-level management to the personnel performing the actual operation. One way of accomplishing

this at the lower organizational levels is to offer incentives for new, innovative ideas for changes which promote pollution prevention. The best way to accomplish this at higher management levels is to demonstrate cost-effectiveness or positive political implications of these changes.

Recommendations

The PPIDM is the first model of its kind and was only tested on a single case study; therefore, it should be studied for a wider range of applicability. For instance, it would be worthwhile to study the possible use of this model in evaluating other types of pollution prevention alternatives. Additionally, a sensitivity analysis of data considerations would be a beneficial step to add to the PPIDM process.

It is also recommended that future research be dedicated to analyses of litigation liabilities, much like the research performed on landfill liabilities referred to earlier in this document. This could become a critical consideration, due to the increasing occurrences of Air Force fines and penalties and individual criminal and civil lawsuits. This increase in occurrences is a direct result of the waiver of Air Force sovereign immunity imposed by the Federal Facilities Act.

APPENDIX

COST CONSIDERATIONS:

Case Study Calculations

APPENDIX: COST CONSIDERATIONS

CASE STUDY CALCULATIONS

INTANGIBLES - LEVEL 1	DCM/PHENOL	SR-125A
IMPROVED PUBLIC IMAGE	NA	5
IMPROVED WORKER ATTITUDE	NA	5
AVOIDED BAD PRESS	NA	4
ENHANCED REGULATOR RELATIONS	NA	4

DEGREE OF IMPORTANCE:
1 = very low
2 = moderately low
3 = average
4 = moderately high
5 = very high

COST CONSIDERATIONS

CASE STUDY CALCULATIONS

PRIMARY TANGIBLES - LEVEL 2	DCM/PHENOL	PMB	CO2	SR-125A
CAPITAL COSTS				
Process Equipment & Training	$0.00	$74,261 (88)	$137,346 (90)	$0.00
Installation	$0.00	$34,857 (88)	$11,476 (90)	$0.00
Engineering	$0.00	80 hr @ $18/hr = $1,440 (88)	50 hr @ $20/hr = $1,000 (90)	$0.00
Equipment Rental	$0.00	$0.00	$12,000/yr	$0.00
Facility & Utility Mods (electrical runs)	$0.00	$3,000	$3,000	$0.00
RAW MATERIALS	$206.25/drum phenol $380/drum DCM [((13+(3/4)2)/KC-135 * 37 KC-135+(16+(3/4)1.5) /B-52* 14 B-52 + 50*(3/4)0.5) * $206.25/drum phenol] + [((12+(3/4)2)/KC-135 * 37 KC-135+(14+(3/4)1.5) /B-52 * 14 B-52 + 50*(3/4)0.5) * $380/drum DCM] = $552,755/yr	$407/250-lb drum ($1.63/lb) 0.95*24,420 lbs waste * $1.63/lb = $37,815/yr	$0.04/lb @ 300 lb/hr @ 50% effic.	$1265/drum = $23/gal (92) [((12+2)/KC-135 * 37 KC-135) + ((17+1)/B-52 * 14 B-52) + 50*0.3] * $1265/drum = $993,025/yr

COST CONSIDERATIONS

CASE STUDY CALCULATIONS

PRIMARY TANGIBLES - LEVEL 2 (CONTD)	DCM/PHENOL	PMB	CO2	SR-125A
UTILITIES				
Electric ($0.04 kW-hr)	$0.00	120 hr/mnth @ 220 V/40 amp = $0.32/hr = $460/yr	8 hr/day @ 480 V/400 amp = $6.91/hr = $13,825/yr	$0.00
Water ($0.0)	$0.00	$0.00	$0.00	$0.00
PRODUCTIVITY				
Manpower (for FY93)				
KC-135				
Aircraft (37 acft/yr)	1040 MH @ $19/hr = $19,760/acft = $731,120/yr	NA	NA	860 MH @ $19/hr = $16,340/acft = $605,580/yr
Components (line generated items)	(363 + (3*36)) MH @ $19/hr = $8949/acft = $331,113/yr	36 MH @ $19/hr = $684/acft = $25,308/yr		300 MH @ $19/hr = $5,700/acft = $210,900/yr
B-52				
Aircraft (14 acft/yr)	950 MH @ $19/hr = $18,050/acft = $252,700/yr	NA	NA	802 MH @ $19/hr =15,238/acft = $213,332/yr
Components (line generated items)	(150 + (3*16) MH @ $19/hr = $3762/acft = $52,668/yr	16 MH @ $19/hr = $304/acft = $4256/yr		128 MH @ $19/hr = $2,432/acft = $34,048/yr
MISTR	(75 + (3*8)) MH @ $19/hr = $1881/wk = $94,050/yr	8 MH @ $19/hr = $152/wk = $7600/yr	NA	40 MH @ $19/hr = $760/wk = $38,000

COST CONSIDERATIONS

CASE STUDY CALCULATIONS

PRIMARY TANGIBLES - LEVEL 2 (CONTD)	DCM/PHENOL	PMB	CO2	SR-125A
POLLUTION MANAGEMENT				
HW Disposal				
Paint Chip Sludge	150,000 lb/yr @ $1.48/lb = $222,000/yr (91)	NA	NA	150,000 lb/yr @ $0.37/lb = $55,500/yr
Plastic / Acrylic Media	NA	24,420 lb/yr @ $1.00/lb = $24,420/yr	NA	NA
End-Of-Pipe Treatment				
Wastewater to IWTP	(45k+2*38.25k)gal/KC-135*37 +(50k+2*42.5k)gal/B-52*14 +(2*250day*20k/day) gal/yr = 16,365,500 gal/yr - 66,000 gal/yr (removed w/sludge) = 16,319,500 gal/yr @ $5/1000 gal = $81,597/yr (91)	NA	NA	5,460,000 gal/yr - 66,000 gal/yr (removed w/sludge) = 5,394,000 gal/yr @ $5/1000 gal = $26,970/yr
Air Emissions (new equipment)	110,000 cfm/exhaust fan (max. pneumatic load) @ 10 exhaust fans = 1,100,000 cfm @ $40/cfm (carbon absorption) = $44,000,000 (FY 95)	NA	NA	NA

COST CONSIDERATIONS

CASE STUDY CALCULATIONS

PRIMARY TANGIBLES - LEVEL 2 (CONTD)	DCM/PHENOL	PMB	CO2	SR-125A
PERSONAL PROTECTIVE EQUIPMENT				
Fresh Air Assembly				
Equipment Maintenance				
Filters	(3 filters) ($75/filter) (4/yr) = $900/yr			
Labor	(6 hrs) ($30/hr) (4/yr) = $720/yr			
Media	(3 media) ($200/ea) = $600/yr			
Labor	(6 hrs) ($30/hr) (1/yr) = $180/yr			
PPE Replacement				
Shrouds	($9/ea) (1/day) (250 days) (39 workers) = $87,750/yr			
Breathing hose	($63.58/ea) (1/yr) (39 workers) = $2,479/yr			
Cooling assembly	($168.58/ea) (1/yr) (39 workers) = $6,575/yr			
Heating assembly	($221.31/ea) (1/yr) (39 workers) = $8,631/yr			
Full Face Respirator				
Filters	($ 2.62/ea) (2/respirator) (1/day) (250 days) (39 workers) = $51,090/yr			
Spectacle Kits	($40.75/ea) * 0.5*6 = $122/yr			
Starter Set	($63.11/set) (6/yr) = $379/yr			
TOTAL	$159,425	<------------------------	0 5*$159,550 = $79,710	---------------->

COST CONSIDERATIONS
CASE STUDY CALCULATIONS

SECONDARY TANGIBLES - LEVEL 3	DCM/PHENOL	SR-125A
POLLUTION MANAGEMENT (Administrative)	NA	NA
CHEMICAL USAGE TRAINING		
Shop Safety	(68 workers) ($19/hr) (12 hrs/yr) = $15,504/yr	
Hazardous Chemical Refresher	(68 workers) ($19/hr) (8 hrs) = $10,336/yr	
Respirator Fit Test	(68 workers) ($19/hr) (4 hrs/yr) = $5,168/yr	
Annual Physical	(68 workers) ($19/hr) (8 hrs/yr) = $10,336/yr	
TOTAL	$41,344/yr	0.5*$41,344 = $20,670
LIABILITIES		
Health Hazards		
Medical Attention	88 medical visits/yr [(0.5*88 visits*$5 25/visit) + (0.25*88 visits*$3.65/visit) + (0.25*88 visits*$8.9/visit)] = $500/yr	0.25*$500 = $125/yr
Time off Work	2610 lost hrs documented * $19/hr = $49,590/yr	0 25*$49,590 = $12,400
Spills	NA	NA
Regulatory Fines and Penalties	NA	NA
Landfills	Missing Data	Missing Data

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Vita

Ms. Clare R. Mendelsohn was born on 6 May 1964 in Seward, Alaska. She graduated from Negaunee High School in 1982. In the fall of that year she began college at Oakland University in Rochester, Michigan. After two years, Ms. Mendelsohn transferred to Michigan Technological University, where she graduated with a Bachelor of Science in Chemical Engineering in May 1987. Ms. Mendelsohn then began her environmental career at Wright-Patterson AFB on a contract with the University of Tennessee through an agreement between the *Departments of Defense and Energy*. At that time, she was assigned to the Installation Restoration Program and was given the responsibility of managing an in situ biological treatment of an underground storage tank fuel spill. In March 1988, Ms. Mendelsohn was hired as a Civil Service employee with the Office of Environmental Management, Engineering Branch, and became the Aboveground and Underground Storage Tank Program Manager. This work involved ensuring compliance with all federal and state regulation of the tanks, and included managing a few million dollar budget annually. In May 1991, Ms. Mendelsohn was then selected to attend the Engineering and Environmental Management masters degree program in the School of Engineering of the Air Force Institute of Technology.

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Vita

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13. ABSTRACT (Maximum 200 words)

This research develops a Pollution Prevention Investment Decision Model (PPIDM) to evaluate the financial feasibility of pollution prevention alternatives. The PPIDM provides managers with simple, systematic, and flexible guidelines for making accurate and expedient decisions when considering pollution prevention alternatives. The model illustrates that a comprehensive analysis is not always necessary. The PPIDM gives managers the flexibility to adjust the economic feasibility criteria based on top management's perceptions of the political environment. When top management places a very high value on political considerations, economic criteria is insignificant and the project may be implemented immediately without further analysis. The PPIDM takes an incremental approach which allows managers to evaluate projects by considering data in increments beginning with management's interpretation of subjective considerations. This approach to project feasibility analysis enables environmental managers to make quicker decisions without sacrificing accuracy. This model also provides guidelines for estimating spill liabilities using probabilistic analysis. This procedure has potential for estimating other liabilities such as regulatory fines and penalties. This research includes an aircraft depainting case study to illustrate the PPIDM and exemplify the benefits of pollution prevention. Although the study specifically addresses Air Force activities, it has universal application.

14. SUBJECT TERMS
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